Species Status Assessment Report

for the

Jemez Mountains Salamander (*Plethodon neomexicanus*)

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U.S. Fish and Wildlife Service

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Recommended reference:

U.S. Fish and Wildlife Service. 2026. Species status assessment report for the Jemez Mountains Salamander (*Plethodon neomexicanus*), Version 1.0. February 2026. Albuquerque, New Mexico.

Table of Contents

1 INTRODUCTION

The Jemez Mountains salamander (*Plethodon neomexicanus*) is endemic to the state of New Mexico and found only in and around the Jemez Mountains in the northern part of the state, specifically in Los Alamos, Rio Arriba, and Sandoval counties. The majority of salamander habitat is located on federally managed lands including United States (U.S.) Forest Service Santa Fe National Forest, U.S. National Park Service Valles Caldera National Preserve and Bandelier National Monument, and U.S. Department of Energy Los Alamos National Laboratory. Sporadic sampling efforts over the last twenty years show that the salamander still inhabits some of these lands.

The Jemez Mountains salamander was proposed as endangered on October 26, 2011 (USFWS 2012; 77 FR 56482) and listed as a species in danger of extinction on September 10, 2013, under the Endangered Species Act (ESA; USFWS 2013a; 78 FR 55600). We designated critical habitat for the Jemez Mountains salamander on November 20, 2013 (USFWS 2013b; 78 FR 69569).

The salamander was originally reported as *Spelerpes multiplicatus* (=*Eurycea multiplicatus*) in 1913; however, it was described and recognized as a new and distinct species (*Plethodon neomexicanus*) in 1950. The salamander is uniformly dark brown above, with occasional fine gold to brassy coloring with stippling dorsally (on the back and sides) and is sooty gray ventrally (underside). The salamander is slender and elongate and has foot webbing and a reduced fifth toe.

The Species Status Assessment (SSA) framework (USFWS 2016a, entire; Smith et al. 2018, entire) is the U.S. Fish and Wildlife Service (USFWS) approach for assessing a species' biological condition. It includes an in-depth review of the species' biology, resource needs, and stressors, an evaluation of the species' current status, and requirements for maintaining a long-term viable population. It also includes information on existing and potential future conservation efforts. The SSA framework uses the conservation biology principles of resiliency, redundancy, and representation (collectively known as the "3Rs;" see definitions below), as a lens to evaluate the current and future condition of the species (Wolf et al. 2015, entire). The result is an SSA report that characterizes a species' ability to sustain populations in the wild over time based on the best scientific understanding of current and future population health, abundance, distribution, habitat, and stressors potentially affecting the species. The SSA report can be used to inform a range of ESA actions, such as listing, consultation, and recovery, and is intended to be updated as new information becomes available.

For the Jemez Mountains salamander, this SSA report will be used to inform development of a recovery plan and future five-year status reviews. The best available information and scientific analyses are contained in this SSA report. The report does not provide decisions; instead, it provides a review of available information related to the Jemez Mountains salamander's current and potential future biological condition for consideration when developing the recovery plan and future five-year status reviews. This report was peer reviewed following guidance provided in the August 22, 2016, Peer Review Process memorandum (USFWS 2016b, entire).

For this assessment, viability is defined as the Jemez Mountains salamander's ability to sustain occupancy in subunits in the wild over time. We will characterize the status of the Jemez Mountains salamander in terms of the 3Rs (i.e., resiliency, redundancy, and representation; Wolf et al. 2015, entire) using the SSA framework to consider what the species needs to maintain viability (Figure 1.1).

- *Resiliency* describes the ability of a population to withstand stochastic events. Highly resilient populations are able to withstand demographic stochasticity (e.g., random fluctuations in birth rates), environmental stochasticity (e.g., random variations in precipitation), or the effects of anthropogenic activities (Smith et al. 2018, entire). Simply stated, resiliency is the ability of a species to sustain populations through the natural range of favorable and unfavorable conditions. We measure resiliency based on metrics of population health (e.g., birth versus death rates and population size).

- *Redundancy* describes the ability of a species to withstand or bounce back from catastrophic events, by spreading risk among multiple populations or across a large area. Catastrophic events may include natural events such as hurricanes or human-mediated events such as large-scale wildfires or oil spills. We measure redundancy by the number of populations and their resiliency, distribution, and connectivity over the landscape (Smith et al. 2018, entire).

- *Representation* describes the ability of the species to adapt to changing environmental conditions. Representation may include genetic or ecological diversity and indicates a species' potential ability to adapt to environmental changes. The more representation or diversity a species has, the more the species is able to adapt to natural or human-caused changes in the environment. In the absence of species-specific genetic and ecological diversity information, we evaluate representation based on the extent and variability of habitat characteristics across the species' geographical range (Smith et al. 2018, entire).

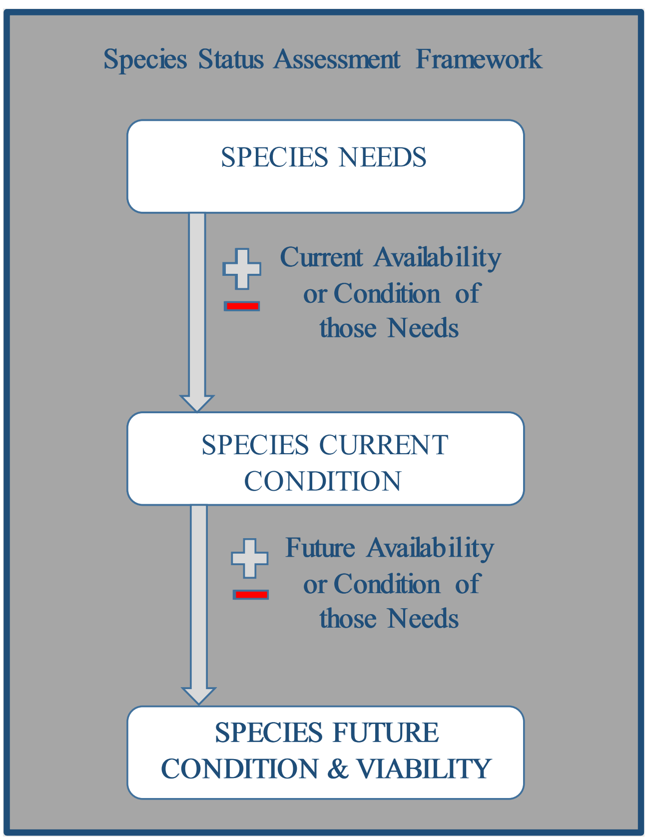

Figure 1.1. Species Status Assessment Framework.

To evaluate the potential future biological condition of the Jemez Mountains salamander, we assessed a range of possible future conditions, including future stressors and conservation actions, to allow us to consider the resiliency, redundancy, and representation of the species into the future. This report assesses the demographic risks and ongoing and future conservation potentially acting on the Jemez Mountains salamander in the context of evaluating the species' viability and extinction risk into the future. The best available scientific and commercial information was used to describe the past, present and plausible future status of the Jemez Mountains salamander.

2 SPECIES ECOLOGY AND NEEDS

2.1 Taxonomy and Genetics

The Jemez Mountains salamander (*Plethodon neomexicanus*; "salamander") is classified in the order Caudata within the family Plethodontidae (Figure 2.1). This salamander was first described in 1950 (Stebbins and Riemer 1950, entire). The holotype is in the Museum of Vertebrate Zoology, University of California, Berkeley, collected by Robert C. Stebbins in 1949. Although E.C. Dunn (1926, p. 316) reported *Eurycea multiplicata* from the Jemez Mountains of New Mexico, the specimens (USNM 42921-2) were later determined to be *Plethodon neomexicanus* (Stebbins and Riemer 1950, p. 73). Additional early records of *Eurycea multiplicata* in the Jemez Mountains exist, including one specimen collected by professor Junius Henderson reported in 1924 (Van Denburgh; p.194). This specimen was one of three individuals collected by professor Henderson in 1910. Two individuals are housed at the National Museum of Natural History and are identified as *Plethodon neomexicanus* (Smithsonian National Museum of Natural History, 2024 and 2025; entire). The third individual was housed at University of Colorado Boulder and went missing from the collection in 1949 (C. Ramotnik, pers. comm.).

Morphological characters are not adequate to differentiate this salamander from all other species of plethodontid salamanders (Stebbins and Riemer 1950, p. 77), but geography is sufficient, as no other plethodontid salamanders are known from the Jemez Mountains.

The genetic variation of 26 species within the genus *Plethodon* was analyzed using electrophoretic analysis of protein sequences (Highton and Larson 1979, p. 581). Originally, the Jemez Mountains salamander was thought to be closely related to the Larch Mountain salamander (*Plethodon larselli*; Highton and Larson 1979, p. 590). These two salamanders are the only salamanders in the genus *Plethodon* with reduced numbers of phalanges (digital bones) in the fifth hind toe. However, more recent research using ND4 mitochondrial DNA from Mahoney (2001, p. 184) indicates that the morphological similarity among these two salamanders is likely due to recency of common ancestry. Mahoney (2001, p. 184) suggests that the Jemez Mountains salamander "does not group with any other lineage". Lastly, unlike many other species in the genus, the Jemez Mountains salamander has not speciated since the Tertiary period (Highton and Larson 1979, pp. 590 and 592).

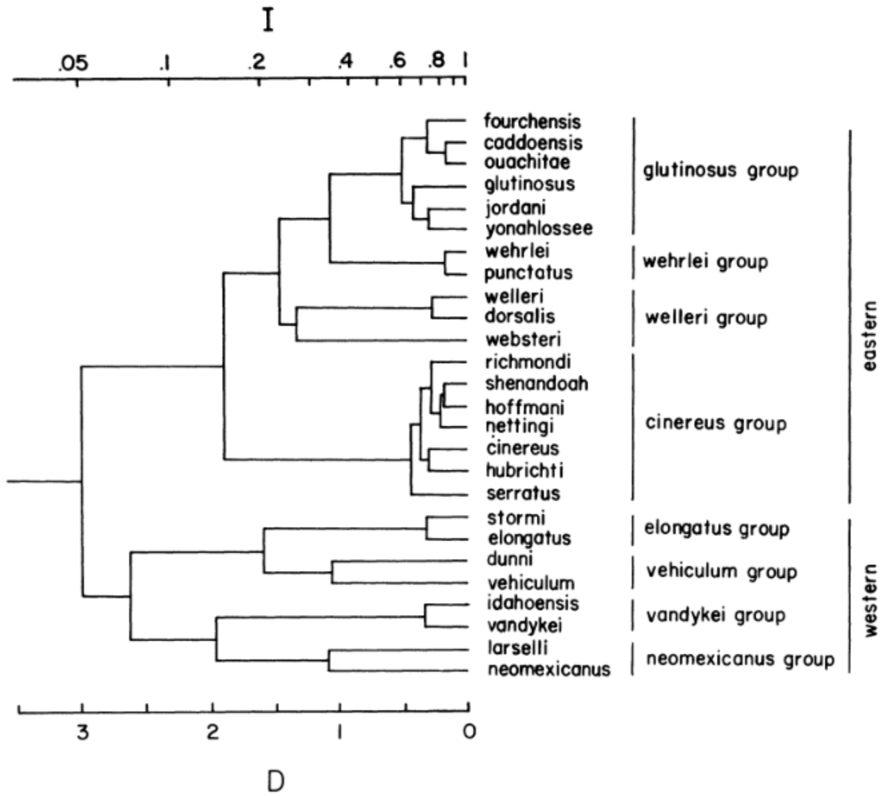

Figure 2.1. The speciation of the genus Plethodontidae (from Highton and Larson 1979, p. 588).

2.2 Species Description

Jemez Mountains salamanders are small lungless salamanders. The species is similar to other *Plethodon* species in that it does not have an aquatic life stage and respiration occurs only through the skin (Carey 1987, p. 2; Ramotnik 1988, p. 1). In adults, the body is dark brown dorsally (back) and grey ventrally (underside), with occasional fine gold stippling along the sides (Stebbins and Riemer 1950, p. 74). Juveniles have dorsal stripes, and the venter of the tail is whitish with a gray cast but otherwise looks very similar to the adults (Stebbins and Riemer 1950, p. 76). This salamander has a slender body, with adults having on average 18 costal grooves (grooves that extend vertically typically from the ventral body surface to the mid-dorsal region, which can be seen between the front and hind limbs in Figure 2.2) and 19 caudal vertebrae (Brodie and Altig 1967, p. 670). The snout to vent length (SVL; measurement from the tip of the nose to distal end of the cloaca) of females is on average approximately 2.21 inches (in) (56.2 millimeters [mm]) and for males is approximately 2.17 in (55.2 mm), with an average total length of approximately 3.24 in (82.3 mm; Williams 1972, p. 15; 1978, pp. 472-473). The smallest known juvenile snout to vent length is 0.67 in (17mm; Williams 1973, p. 131). Historically, sexual dimorphism was thought to be exhibited as a wider snout in males than females (Brodie and Altig 1967, p. 671). However, cloacal characters including distinct papillose tissue in the cloaca and a cloacal cleft in adult males and cloacal rugae (transverse ribbing in the cloacal tube) in adult females can be used to differentiate sex in museum specimens (Karraker et al. 2023, p. 206). The cloacal cleft in males and cloacal rugae in females can also be used to determine sex in larger individuals in the field (Karraker et al. 2023, pp. 206-207).

Figure 2.2. Photo of the Jemez Mountains salamander in the wild. Vertical costal grooves can be seen between the front and hind limbs (photo courtesy of N. Karraker).

2.3 Life History

There are three life stages of the Jemez Mountains salamander: egg, juvenile, and adult (Figure 2.3). Juvenile salamanders hatch following full larval development in the egg and remain reproductively immature until 3 to 4 years of age for females and 3 years for males, after which they are considered adults (Williams 1976, pp. 31 and 35). Although not much is known about the lifespan of Jemez Mountains salamanders in the wild, the recapture of a marked Jemez Mountains salamander indicates they can live at least 14 years (USFWS 2013a, p. 55601). Other *Plethodon* species can live anywhere from 6 to 16 years (Marvin 2001, p. 110). Given this, we assume a lifespan of at least 14 years in the wild for consideration of current distribution of the species in this SSA.

Figure 2.3. Life stages of the Jemez Mountains salamander. *Note: egg mass depicted in diagram is Plethodon albagula, obtained from Trauth et al. 2006, p. 145. Photo credits for juvenile salamander (USFWS), adult salamander (N. Karraker).*

Information in the following sections regarding behavior, reproduction, and movement of Jemez Mountains salamander is taken from a limited number of studies, many of which were conducted several or more decades ago and precede the current environmental conditions (e.g., high-severity fire and drought) and land cover changes associated with development, wildfires, higher temperatures, and changes in precipitation. Thus, as land cover and climatic conditions change, the species' ecology that we reference may have shifted (e.g., if current spring daytime air temperatures are warmer than in the 1960's, the period of surface activity from the 1960's, as based on thermal limits, may no longer apply). However, until new information becomes available, these data represent the best available science.

2.3.1 Behavior

Jemez Mountains salamanders are thought to spend most of their lives underground. They have been documented aboveground on the forest floor from May to November (NHNM, accessed August 24, 2021), but salamander activity primarily coincides with the monsoon season (approximately June - September) in New Mexico. In recent years, the salamander has been found on the surface during only the wettest portions of the monsoon season in July and August. During this time aboveground, breeding likely occurs (Williams 1976, p. 4). Limited evidence suggests this species is nocturnal, with salamanders being observed on the forest floor after total darkness (Reagan 1972, p. 489). Foraging occurs while aboveground (Reagan 1972, p. 489; Cummer 2005, p. 43), and non-foraging individuals are found underneath and within rotting logs, beneath rocks, and in crevices in talus slopes (Reagan 1972, pp. 488-489; Carey 1987, p. 11). Jemez Mountains salamanders are ectothermic (meaning they cannot physiologically regulate their body temperature); thus, temperature and moisture often drive salamander behavior and physiology, and they tend to choose cover objects that help them retain moisture and stabilize their internal temperature (Carey 1987, p. 9). Consequently, increases in temperature and decreases in moisture/increases in drying can greatly impact the species' demographic attributes (e.g., reproductive success and salamander survival) primarily by influencing when and the amount of time that salamanders can be aboveground (see Figure 5.1 for more information).

2.3.2 Reproduction

Although this salamander spends most of the year underground (Reagan 1967, p. 25), reproduction likely happens aboveground (Degenhardt et al. 1996, p. 28). Reproduction likely occurs in July and August during the monsoon season when the ground is wet enough for the salamanders to move to the surface without desiccation (Williams 1976, p. 4). During reproduction, male and female salamanders interact, with the male enticing the female to pick up his spermatophore and store the spermatophore within the female's spermatheca (Williams 1976, p. 35). Based on the work of Reagan (1967, pp. 31-32) and Williams (1978, p. 475), gravid females appear to move back underground after fertilization, as none were found on the surface after mid-August. Williams (1978, p. 475) reports that females "appear to oviposit every other year," which suggests that females may store sperm for at least two years. Gametes in male and female salamanders develop during the previous monsoon season, but females produce eggs only every other year (Williams 1972, pp. 20 and 24). Sexual maturity in this salamander is reached at 3 to 4 years in females and 3 years in males (Williams 1976, pp. 31 and 35).

Reagan (1967, pp. 31-32) counted 5 to 12 enlarged follicles (over 2.0 mm in diameter) in the ovaries of 45 females with a mean of 7.7 eggs. Williams (1978, p. 475) reported 16 adult females with maturing ova that ranged in diameter from 0.043 in (1.1 mm) in mid-June to 2.1 mm in mid-September. He also found the number of maturing eggs over 0.039 in (1.0 mm) in diameter averaged 7.7, which was similar to the count by Reagan (1967, p. 32). As noted by Reagan (1967, p. 32) and Williams (1978, p. 475), females will lay up to 8 eggs sometime between mid-August and the following spring (e.g., April or late May). Jemez Mountains salamander has one of the largest eggs in the genus *Plethodon,* with an average diameter of 0.27 in (6.9 mm), and has one of the smallest clutch sizes among salamanders in the genus *Plethodon* (Williams 1972, pp. 24 and 31; Williams 1978, p. 475). No eggs have been found during field surveys, leading researchers to suspect they are deposited underground (Reagan 1972, p. 490; Williams 1978, p. 474). Reagan (1972, p. 490) suggested that this salamander probably "deposits its eggs in rock cavities deep in the talus slopes." One clutch of eggs, attached to the sides of pieces of wood by a stalk or peduncle, was laid in captivity in June; this clutch included seven eggs averaging 0.27 in (6.9 mm) in diameter (Williams 1978, p. 474).

The average SVL of mature males (with testes) is ~2.2 in (55.2 mm) and lengths ranged from ~1.9 to 2.5 in (47 to 63 mm: Williams 1978, p. 472). As males mature, spermatozoa are formed in late August and fill the testes in early fall. Sperm is transferred to the vas deferens in late fall to winter, where it is stored until mating season (from June through September). After mating, sperm will stay in the vas deferens until the end of September (Williams 1978, pp. 472-473).

2.3.3 Diet

Evidence of diet has been gleaned from the types of invertebrates found within the stomachs of Jemez Mountains salamanders (Reagan 1972, p. 489; Cummer 2005, p. 43). Most salamanders that have been evaluated in studies of food habits have been captured above ground, so very little information is known about their diet or feeding habits while they are underground (Reagan 1972, p. 489). Reagan (1972, p. 489) recorded a distribution of food items from 39 salamanders, and nearly 75 percent of food items belonged to the Class Insecta: beetle larvae (Coleoptera), fungus gnats (Diptera – Mycetophilidae), ants (Hymenoptera – Formicidae), and butterfly/moth larvae (Lepidoptera). Additionally, Cummer (2005, p. 43) assessed the stomach contents of 79 salamanders and identified 19 prey categories, with three groups – ants, mites (Acari), and beetles – being recognized as more important (most numerous, most voluminous, and most frequent) than other groups. Additionally, Cummer (2005, pp. 45-50) found that specialization on any particular invertebrate taxon was unlikely, but there was likely a preferential selection of prey categories (ants, mites, and beetles).

2.3.4 Movement

Ramotnik (1988, p. 27) reported that individual distances salamanders moved aboveground between consecutive observations ranged from 0 to 43 ft (0 to 13 m) and that 73 percent of recorded movements were less than 3.3 ft (1 m). In 59 of 109 observations, salamanders had not moved between observations. When the zero-distance movements were excluded from analysis, the average distance salamanders moved was 7.8 ft (2.4 m), and the greatest total distance per number of days detected was 144 ft (43.9 m) over 22 days (Ramotnik 1988, p. 28). Ramotnik (1988, p. 32) also estimated the home range of six salamanders with these data and reports the average home range was 86 square feet (ft^2) (8.0 square meters (m^2)); males had a larger home range (137 ft^2 [12.7 m^2]) than females (78 ft^2 [7.2 m^2]). Although the small sample size associated with this study precluded detecting significant differences in movement and home range (n=9; Ramotnik 1988, pp. 27-28), the data are still useful in understanding the potential for salamander movement. Individuals with larger home ranges (greater than 54 ft^2 [5.0 m^2]) were often found returning to the same cover object, whereas individuals with home ranges less than 54 ft^2 (5.0 m^2) rarely returned to the same spot (Ramotnik 1988, pp. 32-37). During a 10-year study, the New Mexico Department of Game and Fish (2000, p. 15) found the average distance of 32 movements of salamanders recaptured either in the same year or between years within a 164-ft-by-164-ft (50-m-by-50-m) plot, was 19.6 ft (5.98 m), with a maximum distance moved from original capture site of 60.7 ft (18.5 m). During the same time span, one salamander was observed near the same log nearly 5 years later (NMDGF 2000, p. 16). For PIT-tagged salamanders tracked from 2019-2021, individual movements of 3-6 ft (1-2 m) were documented occasionally. In 2020, three individuals moved larger distances. In July 2020, a male salamander moved 21.0 ft (6.4 m) over a four-day period, and a female moved 26.6 ft (8.1 m) over a six-day period. In August 2020, a female moved 43.3 ft (13.2 m) over a four-day period, with the movement coinciding with a significant rain event (N. Karraker, pers. comm.). The data from these studies indicate that Jemez Mountains salamanders exhibit philopatry to cover objects and occupy relatively small home ranges but can occasionally make longer movements.

Ramotnik (1988, p. 30) found more salamanders above ground on north-facing slopes within and under logs (Douglas-fir [*Pseudotsuga menziesii*], white fir [*Abies concolor*], spruce [*Picea sp.*], and pine [*Pinus sp.*]), and under rocks when the air temperature was < 15°C (59°F). When she surveyed south-facing slopes, most of her detections were of salamanders underground. Ramotnik (1988, p. 30) found salamanders underground when air temperatures were >15°C (59°F); however, no salamanders were found above ground once the temperature exceeded 20°C (68°F). Rainfall also influenced salamander detections, with a greater percentage of detections occurring underground when no rain had fallen during the previous 24 hours, while minimal amounts of rainfall (less than one centimeter [cm]), resulted in a greater percentage of salamander detections within, or under, logs and rocks on the surface (Ramotnik 1988, p. 30).

2.4 Habitat

2.4.1 Foraging and Breeding Habitat

Jemez Mountains salamanders are endemic to the Jemez Mountains in upper montane forests ranging in elevation from 2140-3429 meters (m; 7021-11,250 feet [ft]) (Reagan 1972, p. 487; Whitford and Ludwig 1976, p. 120). Historical surveys reported that salamanders were found on isolated north-facing slopes, sheltered canyons and in forest edges and along the edge of montane meadows (Reagan 1972, p. 487). More recent survey efforts, however, have detected Jemez Mountains salamanders primarily within interior forest areas (N. Karraker, pers. comm.).

Forest composition in historically occupied salamander habitats is primarily coniferous trees, including Douglas-fir, white fir, Engelmann spruce (*Picea engelmannii*), blue spruce (*Picea pungens*), and Ponderosa Pine (*Pinus ponderosa*). Other non-coniferous trees, including Rocky Mountain maple (*Acer glabrum*) and quaking aspen (*Populus tremuloides*), can also be common (Reagan 1972, p. 487). Everett (2003, p. 24) recorded dominant woody vegetation of Douglas-fir (34%), pine (23%), and white fir (20%), within sites with salamander captures, and canopy cover ranged from 14.04 to 99.84 percent and averaged 58.24 to 94.29 percent. Salamanders have rarely been found in stands dominated by Ponderosa pine in recent surveys. However, substantially more survey effort has been expended in higher elevation, mesic mixed conifer forests and in wetter, northerly-facing slopes of canyons than in Ponderosa pine forests in recent years (N. Karraker, pers. comm.). Within mixed-conifer forests, salamanders are typically found on north-facing steep slopes averaging 30 degrees (range 5 to 36 degrees) from horizontal, with the presence of underlying volcanic rock (Reagan 1972, p. 488; Ramotnik and Scott 1988, p. 59). Everett (2003, p. 24) found salamanders on slopes greater than 30 degrees that were north- (32% of observations), east- (18% of observations), or west-facing (41% of observations) and greater than 2195 m (7200 ft) in elevation. Large numbers of salamanders were historically found on talus slopes, likely due to the loose nature of the rocks and accessible refugia they provide (Reagan 1972, p. 488). Cover objects used by salamanders include decomposing conifer logs, rocks, and burrows within talus slopes (Carey 1987, p. 11; Ramotnik and Scott 1988, p. 57).

Reagan (1972, p. 488) assessed cover objects and reported that salamanders prefer conditions under cover objects approaching 100 percent relative humidity, with substrate temperature ranging between 10.5°C to 13°C (50.9°F to 55.4°F). Additionally, he found that the substrate material in areas where salamanders were found contained mainly needles from white fir, Ponderosa pine, and other fir species, with some deciduous leaves from Rocky Mountain maple and quaking aspen, and an average litter depth of ~2.4 in (6 cm). The soil in these areas was an acidic podzol, likely due to the abundance of pine trees (Reagan 1972, p. 488).

2.4.2 Aboveground Period

Jemez Mountains salamanders are active on the surface when soils are sufficiently warm and moist (Degenhardt et al. 1996, p. 28). It is presumed that the aboveground period is mainly for feeding and mating (Williams 1976, pp. 31-36; Cummer 2005, p. 40). Reagan (1972, p. 489) found salamanders traveling on the forest floor at night when the surface was wet after heavy rain. Conditions conducive to aboveground activity often start in late spring and continue into early fall, which coincides with the monsoon season in New Mexico. During this time, salamanders are found mostly under coarse woody debris (including coniferous and deciduous logs) and small rocks, or in burrows in talus slopes (Carey

1987, p. 11; Ramotnik and Scott 1988, p. 57). During Ramotnik's (1988, p. 17) study, all salamanders (76 total) found were associated with coniferous logs. Salamander association with decomposing coniferous logs seems to be related to the formation of longitudinal cracks with decomposition, in contrast to decomposing deciduous logs which turn into a pulpy mass (Ramotnik 1988, p. 53). Another study (Karraker 2018, entire) established nearly 1000 artificial cover objects to test if Jemez Mountains salamanders would use them, and while they did detect seven salamanders on sites with artificial cover objects, no salamanders were detected under artificial cover objects; this finding contrasts with other species which have been found under artificial objects (e.g., eastern red-backed salamander *Plethodon cinereus*; Moore 2009, entire). Surveys from 2020-2022 yielded 105 salamanders, of which 52 percent were found under logs, 45 percent were found under rocks, and 3 percent were found under bark (N. Karraker, pers. comm.). Together, these studies show that logs and rocks are important; however, it is hypothesized that other items can serve as cover objects for salamanders.

2.4.3 Below Ground Period

Reagan (1972, p. 488) found that from September through May, salamanders typically stayed underground, although salamanders have been observed on the surface in May through November (NHNM accessed August 24, 2021). Salamanders were observed in tunnels within talus slopes several centimeters under the humus layer. In a lab setting, these salamanders created networks of tunnels in the soil underneath rocks in a terrarium (Reagan 1972, p. 489). In the field, salamanders have been observed in tunnels up to one meter below the surface (Reagan 1972, p. 488). Jemez Mountains salamanders lack physical digging attributes, such as claws, which suggests that they are not robust diggers and that interstitial spaces may be used to facilitate below ground movements. Subsurface geology has been found to be an important predictor of salamander presence. Bartlow et al. (2022, pp. 3-7) reported that the Otowi and Tshirege Members of the Bandelier Tuff Formation and the Paliza Canyon Formation andesite account for the majority of salamander occurrence localities. Salamander occurrences were found in proportion to the amount of Qbt (Quaternary Bandier Tuff, Tshirege Member), and were more numerous in subsurface geologies Qbo (Bandelier Tuft, Otowi Member), Tpa (Tertiary Two-pyroxene andesite, undivided), Qcbt (Quaternary Colluvium), and Ttcg (Tertiary Cerro Grande dacite), relative to their availability in the study area (Bartlow et al. 2022, pp. 3-13).

2.5 Species Needs

The following table describes the resource functions associated with resources needed by each life stage of the Jemez Mountains salamander (Table 2.1). Resource functions within the table include B for breeding, F for feeding, and S for sheltering. Descriptions of resource needs are found in "section 2.3 Life History" and "section 2.4 Habitat", above.

Table 2.1. Jemez Mountains salamander resource functions associated with resources needed by each salamander life stage. B = Breeding, F = Feeding, and S = Sheltering. Note: For additional information, see sections 2.3 Life History and 2.4 Habitat, above. The asterisk (*) designates uncertainty if the resource function is important at these life stages. There is anecdotal evidence that other salamander species feed underground, but no evidence that Jemez Mountains salamanders feed while underground.

Resource	Eggs	Juveniles	Adults
Moderate temperatures of 43 to 63 degrees Fahrenheit (soil and air; Williams 1972, p. 18)	S	F, S	F, S, B
Moist environment/relative humidity (approaching 100 %; Reagan 1972, p. 488) /precipitation	S	F, S	F, S, B
Available prey		F, S	F, S
Underground refugia (e.g., rotten root canals, interstitial spaces between rocks, etc.)	S	F*, S	F*, S
Aboveground cover objects (e.g. rocks and woody debris)		F, S	F, S, B

3 DISTRIBUTION

The Jemez Mountains salamander's historical and current distribution and abundance are covered in this chapter. A review of the historical distribution of the species is followed by information on the current distribution.

3.1 Historical Distribution

Conservatively, the Jemez Mountains salamander has likely occupied the Jemez Mountains for at least 10,000 years and potentially as long as 1.2 million years, colonizing the area after volcanic eruption (USFWS 2013a, p. 55601). As listed above in section 2.1Taxonomy and Genetics, the first known specimens of Jemez Mountains salamander from the Jemez Mountains were collected by Henderson in 1910 (Van Denburgh 1924, p.194; Smithsonian National Museum of Natural History, 2024 and 2025; entire). Surveys for the salamander have been sporadic, with periods of intensive annual surveys and periods of limited surveys. Survey methodologies have also varied over time since the species was discovered. Approximately 40 years of historical survey data exist (prior to 1987) collected by multiple biologists and researchers. While these data provide important early records of salamander occurrence, they include a mix of observational and visual survey information collected without a set protocol or data standard. Starting in 1987, NMDGF initiated three survey protocols to improve monitoring efforts (NMDGF 2000, p. 2). These protocols are still in use today and have resulted in approximately 35 years of additional salamander data that provide detection information at specific sites for given points in time.

Additionally, an ongoing 5-year research program has consistently used standardized protocols to survey historical sites and monitor the salamander at a subset of those sites (USFWS 2024, entire).

1987 Survey Protocols (still used today):

- Protocol A (presence or absence) has been used when attempting to determine whether an area is occupied. Following this protocol, surveys cease after three ‘‘person-hours’’ of effort (e.g., one person searching for 3 hours or three people searching for 1 hour) or when the first salamander is observed, whichever comes first.

- Protocol B (population levels and trends) has been used for comparing plots, monitoring trends through time, or evaluating how salamander localities fluctuate in response to environmental variables. For this protocol, a survey is conducted for two person-hours, with all salamanders tallied.

- Protocol C (detailed environmental data) collects microhabitat data to characterize potential salamander habitat. This protocol involves collecting data on important habitat features within a 160 ft (50 m) by 6.6 ft (2 m) transect, in addition to surveying for salamanders under cover objects.

Historical (records prior to 1987) and more recent (records after 1987) salamander detection data are stored with the University of New Mexico, Natural Heritage New Mexico program.

In 2021, the New Mexico Ecological Services Field Office was asked by USFWS headquarters to help develop the Species Range Project (SRP or One Range) for the Jemez Mountains salamander. The SRP is a project launched by the USFWS to improve the way we determine where listed species occur so that we may better protect them. Additional information on the SRP can be found at the Refined Species Range Maps webpage. Using historical salamander survey data, aspect, slope, percent tree canopy cover, depth to bedrock, and average annual precipitation (from 1981 – 2010), a One Range map for the salamander was created. The One Range map is used in this SSA as the description of historical distribution (Figure 3.1).

The historical range includes the Jemez Mountains in and around Los Alamos, Rio Arriba, and Sandoval counties, New Mexico. Historical survey data indicate that the salamander predominately occurs above approximately 2,220 m (7,200 ft) in mixed conifer forests (Degenhardt et al. 1996, p. 28).

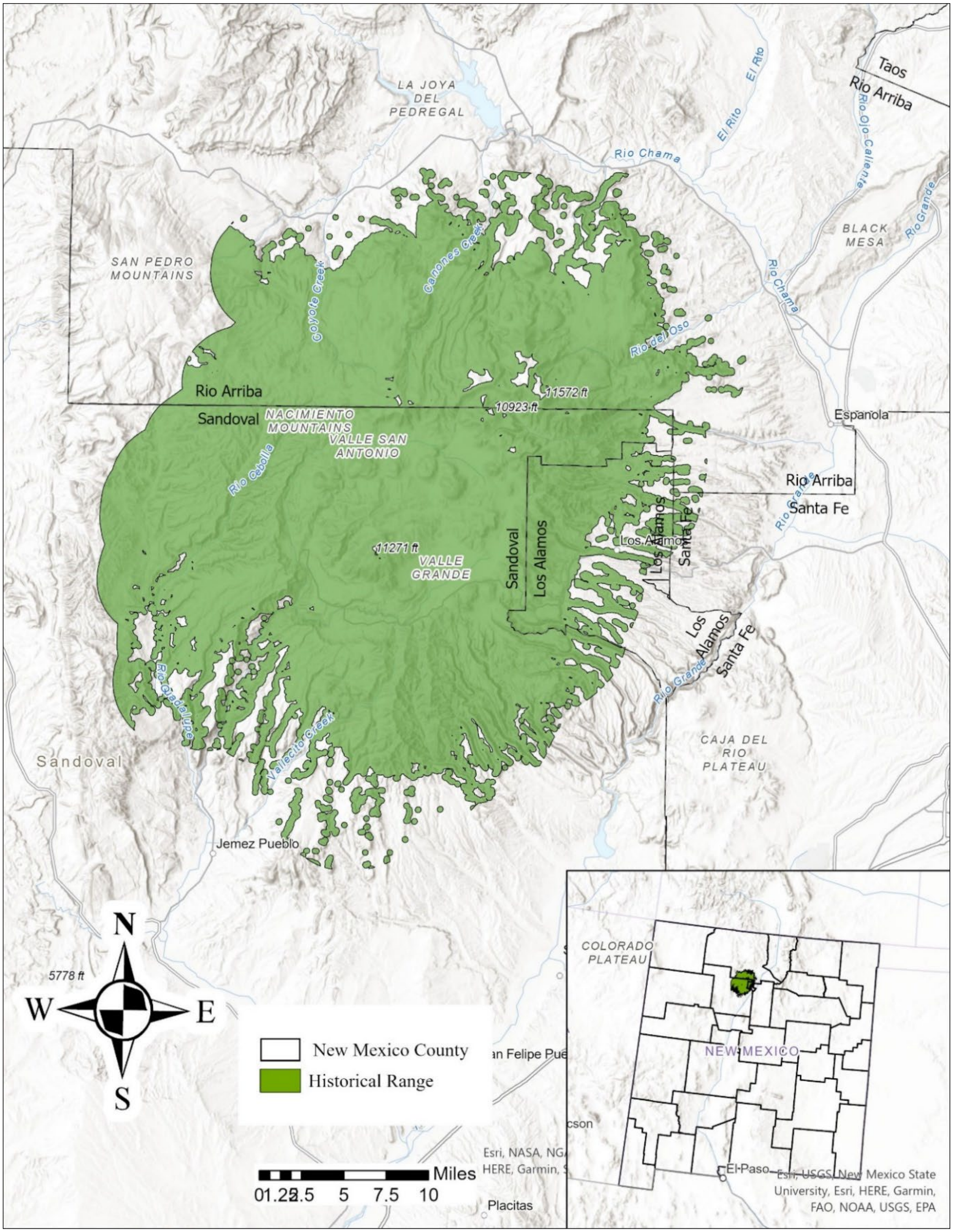

Figure 3.1. USFWS Jemez Mountains salamander One Range map. The One Range map was completed in 2021 based on historical and current salamander survey data (based on all known salamander data up to 2021), aspect, slope, percent tree canopy cover, depth to bedrock, and average annual precipitation (from 1981 – 2010) and is used in this SSA as our understanding of the species' historical range.

3.2 Current Distribution and Salamander Detections

3.2.1 Assumptions and Data Limitations

Our understanding of the salamander's current distribution is limited. Since its discovery, survey efforts have not comprehensively surveyed areas throughout the species' range. In recent years, survey efforts have largely been associated with research, and these surveys, using the standardized protocols described above, have focused on continued monitoring of known salamander "hotspots" (locations where salamanders have been reliably found over the last several years); historically occupied sites which have not recently been surveyed; and sites with apparently suitable habitat for which previous surveys are not known to have been conducted. While there have been efforts to survey in currently unknown, but historically occupied areas, these initiatives have been complicated by data discrepancy issues. In many of these cases, salamander detections were summarized or pooled by site and reported as one centroid location, or in some cases original data were lost. This reporting mechanism likely altered the accuracy and precision of points used to identify historical survey areas. Due to the limited dispersal distance of this species, these data discrepancy issues limit our ability to understand whether survey locations with no recent detections (salamander absence locations) were ever historically occupied.

Detections have recently been made at some sites identified as historically occupied, but for which surveys had not been undertaken for many years. For example, during surveys in 2021, salamanders were detected at 2 of 39 (5%) of historically occupied sites reported as centroids. In 2022, salamanders were found at 5 of 74 (7%) of historically occupied sites precisely reported. Thus, of 113 historically occupied sites surveyed in 2 recent years, salamanders were detected at 6 percent of sites (N. Karraker, pers. comm.). It is important to note that the lack of detections at historically occupied sites may mean that salamanders no longer are present at the site or that salamanders still occupy the site, but the surveys failed to detect them. Giermakowski and Neville (2019, pp. 6-7) reported low detection probabilities for Jemez Mountains salamanders across the species range (0.124 [Confidence Interval (CI) 0.0421 – 0.1661] using the Los Alamos National Laboratory's survey dataset and 0.135 [CI 0.0517 – 0.1867] using the study's full dataset). The ecology of this species further obscures our understanding of the species' distribution. As discussed in chapter 2 SPECIES ECOLOGY AND NEEDS, the Jemez Mountains salamander is small, spends a substantial amount of time underground, surfaces only during a specific time of the year when specific conditions (cool and moist) exist, and relies on cover objects to provide shelter and needed microclimate when aboveground. Combined, these traits limit our ability to reliably detect the salamander when conducting surveys. Surveys are planned during times when salamanders are likely to be above ground. However, optimal conditions (e.g., temperature, recent rains, etc.) may not be present when surveys are conducted and some cover object types, such as decaying logs and deep talus, preclude detections because the salamanders may be within, not under, the object.

Due to the lack of systematic surveys across the species' range and the difficulty of species detection, we do not have data to accurately assess the current distribution of the species. Therefore, here we describe current distribution based on Jemez Mountains salamander detections documented within a 14-year time span (from 2008 – 2021), which is the estimated lifespan of the species. We assume that a single detection of a salamander over this time span conveys our best understanding of where the species may occur today and acknowledge that salamanders may not persist in all locations or may be present in unsurveyed areas. Wildfires have impacted some areas after salamander detections. The areas (hereafter referred to as "subunits") identified as currently occupied reflect our best understanding of the current distribution of the species.

3.2.2 Geographic Units and Subunits

Taking into consideration our limited understanding of Jemez Mountains salamander current distribution, and the SSA's objective of better informing species recovery, the SSA core team has evaluated the current and future conditions of the salamander using a combination of historical data, current detections (those from 2008-2021), and site information about unknown but potentially occupied areas (Figure 3.2) within the probable species historical range. As such, our analyses include not only currently and historically occupied habitats, but also those habitats determined through our analyses as likely to provide adequate habitat for the salamander based on biotic and abiotic factors within the known range of the species. To identify this analysis area, we used historical and recent survey data in combination with subsurface geological information associated with GPS location data (2000- 2022), similar to work done by Bartlow et al. (2022, entire). Areas within the outer bound of the identified analysis area that extended below 2103 m (6900 ft), which are below the elevational threshold for Jemez Mountains salamanders, or areas that include Tribal lands, were subsequently removed.

We divided the identified analysis area into five Geographic Units (Unit[s]; Figure 3.2) using land ownership and features identified as likely barriers to salamander movement (i.e., perennial waterways, then roads (from most to least improved)). Studies on the red-backed salamander (*Plethodon cinereus*), a congener species, suggest that roads and low-order streams are at least a partial barrier to movement for terrestrial salamanders (Marsh et al. 2005, p. 2007 and Marsh et al. 2007, p. 324). The five Units range in size from approximately 42,000 to 68,000 acres (ac; 16,997 to 27,519 hectares [ha]) and allow us to assess the species' representation. The Units are large in comparison to the species' dispersal capabilities and thus may capture genetic or ecological variability across the species' range.

The Units were further divided into subunits. Within each unit, features used to complete the subunit boundaries included other perennial waterways, roads, intermittent or ephemeral stream segments upstream of perennial reaches, and topography such as ridges and valleys. These features are potential barriers to or may inhibit salamander movement. Use of these features resulted in the designation of 34 subunits, six or seven subunits in each Unit (Figure 3.2).

Because we lack sufficient data to understand what constitutes Jemez Mountains salamander populations, this SSA will assess resiliency at the subunit level. We use subunits as surrogates for salamander populations, and we assume that the features identified as likely barriers to movement limit but do not exclude all movement of salamanders between subunits. Roads, used to accomplish various forest management activities including fire suppression and control, are found throughout the range of the Jemez Mountains salamander including along perennial waterways. Our use of roads to delineate subunits allowed for designation of areas, used as surrogates for populations, that can be influenced or protected by forest management practices. While defining populations of salamander is the ideal method for assessing population resiliency and species' representation, in the absence of data to define salamander populations, the use of subunits allows us to evaluate the status of smaller areas and better direct future recovery efforts. Estimates of population resiliency and species' representation may change over time as new information is available on how to better define salamander populations.

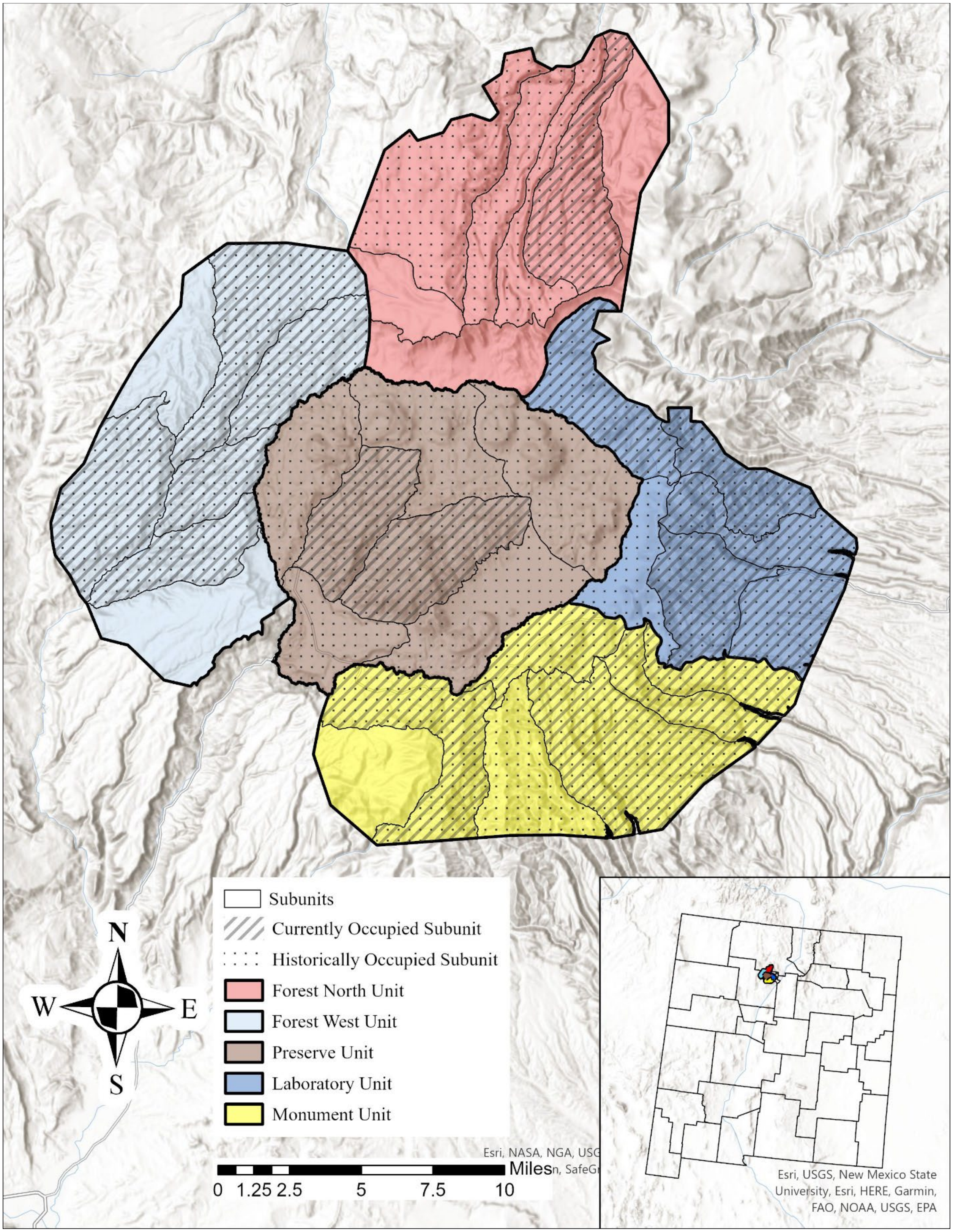

Figure 3.2. Current distribution of Jemez Mountains salamander (using detection information from 2008 to 2021).

3.2.3 Estimates of Current Distribution

Using all historical detections, Jemez Mountains salamanders were historically present in 28 of the 34 subunits identified. Data from surveys conducted between 2008 and 2021 determined that 18 of the 28 subunits included at least one known recent (14 years from 2008-2021) salamander detection (Figure 3.2), suggesting that the salamander's range may have contracted by as much as 36 percent. Based on the current distribution as defined in this SSA, six subunits lack historical Jemez Mountains salamander detections. These subunits contain elevation, geological, and aboveground habitat features considered to be important for Jemez Mountains salamander persistence (Reagan 1967, entire; Ramotnik 1988, entire; Everett 2003, entire; Bartlow et al. 2022, entire). The USFWS is working with partners to catalogue and examine negative survey efforts for Jemez Mountains salamanders (surveys where no salamanders were detected); however, that information is not yet available for use currently.

As discussed in section 3.1 Historical Distribution above, Jemez Mountains salamander surveys have been sporadically conducted over the years since the species was first described by science, and survey methodologies have varied over time. Historical survey data (prior to 1987) were collected via a mix of observational and visual methods without a set protocol or data standard. More recent survey data (1987 to present) were collected using the protocols listed in section 3.1 Historical Distribution. Although survey methods varied and survey effort prior to 1987 is not known, the raw data (salamander counts per survey date) suggest that salamander densities may have declined over time (Figure 3.3). This assumption, moreover, is supported by expert observations made over recent decades. For example, more than 40 salamanders were documented at one location in the 1990s. By comparison, the total number of salamanders documented across all locations for the 2022 season was 32 individuals. The USFWS does not have access to many of the field notes for data prior to 1987, so it is unknown if search effort could be determined from the data, but this warrants further investigation. If sufficient information can be obtained from field notes, statistical analyses may be possible and provide a better understanding of range contraction and declines.

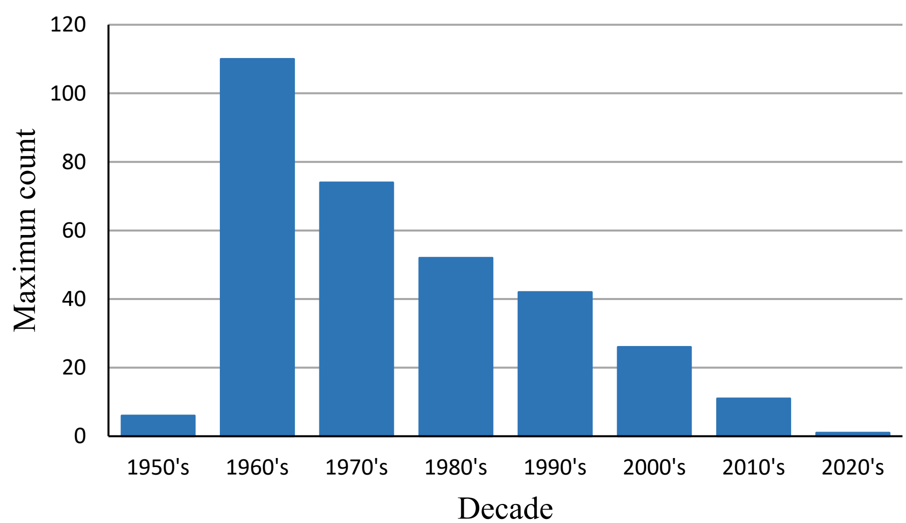

Figure 3.3. Maximum number of Jemez Mountains salamanders detected at a single location during a survey by decade. Note: Although the species was known, attempts to locate the salamander prior to the 1960s were few.

Current distribution information is provided in Table 3.1, below, showing each Unit, Unit size in acres, land ownership within the Unit, total number of subunits, decade of oldest historical salamander detection, year of most recent salamander detection, number of currently occupied subunits, and number of historically occupied subunits. Conditions within these subunits will be described in more detail in chapter 4 CURRENT CONDITION. The information in Table 3.1 will help to inform discussions with respect to the 3Rs, stressors, and future scenarios (land ownership for management activities in subunits).

3.2.4 Previous habitat and population modeling efforts

Multiple modeling efforts, using various population or occupancy methods, have been conducted for the salamander. Below are short summaries for each effort based on information available, including correspondence and journal articles.

Rocky Mountain Research Station (RMRS model; Bird and Baggett 2012, entire)

The RMRS analysis focused on a region of sixteen USGS quadrangles near Los Alamos, NM and estimating salamander occupancy status. Based on the available data (which included presence and absence data), a single survey occupancy model (SSO model; Lele *et al.* 2012, entire) was selected that would estimate both occupancy and detection probabilities. Using this model was preferred since the observed status was not equivalent to the actual occupancy (from traditional logistic regression [TLR] analysis) and because detection probabilities less than one are not allowed for TLR analysis. Additionally, the TLR analysis can result in biased parameter estimates and underestimated true occupancy statuses (MacKenzie et al. 2002, entire). Typically to estimate detection and occupancy, multiple surveys are needed; however, the SSO model replaces the repeated measures with two conditions 1) one numeric covariate that affects occupancy and detection must exist, and 2) one numeric covariate that is unique to the occupancy and detection parts of the model. For this SSO model, the modelers used standardized elevation, and both aspect (as cardinal direction) and geology were unique to the occupancy side of the model. The SSO model did have inconsistences in the geology information used for the model and with the available salamander data (including the inclusion of salamander absence locations).

The Nature Conservancy (TNC model, Mayer et al. 2012, entire)

The TNC model analysis focused on modeling habitat suitability with salamander presence-only data along with several covariates including elevation, slope, aspect, temperature, precipitation, geology, vegetation, and soil properties using a MaxEnt model (a type of machine learning Species Distribution Model). The MaxEnt model uses species distribution from presence-only data to produce a qualitative "suitability index" rather than a quantitative probability distribution (Mayer et al. 2012, p 7). This modeling effort includes many covariates, identifies important covariates, and removes the unimportant ones for the final result. The important covariates for salamander were identified as geology, July-September precipitation, and a number of soil characteristics. The MaxEnt model map has a similar overlap to the RMRS map, but the authors noted that it was "significantly more restricted in high probability areas" (Mayer et al. 2012, p 2). The MaxEnt model map did overlap "quite well" with the RMRS model when run using only elevation, aspect, and geology covariates. However, much like with the RMRS model there were some limitations with this modeling effort that may lead to misinterpretation of MaxEnt's results. These limitations included 1) small datasets can cause issues since MaxEnt uses a non-standard exponential distribution function which must be offset with a logistic transformation (thus not a true probability of occurrence and more like a qualitative 'suitability index'); 2) important covariates underestimation since MaxEnt uses 'regularization' procedure for small datasets to scale certain covariates effects to prevent overfitting due to large effects of dominant covariates, all of which may skew the output distribution; and 3) since MaxEnt doesn't use absence data, it calculates background points to represent a covariate range for the landscape which can be a problem if these points do not represent actual covariates.

Los Alamos National Laboratory model (LANL model; Bartlow et al 2022, entire)

The LANL model analysis also used MaxEnt to assess how multiple variables influenced the salamander's distribution. These variables included: 1) unit classification based on 1:24,000 scale geologic maps, 2) distance to boundary of mapped geologic contacts within the Valles caldera region, 3) high-resolution elevation, 4) slope, 5) topographic characterization from a LiDAR-derived digital elevation, 6) total precipitation in summer, 7) total precipitation in winter, 8) maximum temperature in winter, 9) minimum temperature in winter, 10) minimum temperature in summer (Bartlow et al. 2022, p. 4). This model used most of the current salamander designated critical habitat not including the northern part of the western designated critical habitat unit since fine-scale geological data was not available. The same limitations mentioned for the TNC model are likely for this effort also. In addition to these limitations, the LANL model does not fully cover the Jemez Mountains salamander historical distribution identified in this SSA.

The above modeling efforts modeled habitat or distribution of the Jemez Mountains salamander across portions of, but to our knowledge not all the area analyzed in this SSA (Figure 3.2); a larger analysis area was desired for future range-wide recovery planning and implementation. The previous modeling efforts incorporated multiple variables such as elevation, geology, precipitation, temperature, etc., some of which were considered during development of the SSA analysis area and future condition assessments. While developing the SSA analysis area consideration of multiple variables lead to the development of 5 geographic Units and 34 subunits (see section 3.2.2 Geographic Units and Subunits). The current SSA analysis area and variables (i.e., forest type, tree density, and vegetation height) were used by the SSA core team to develop the favorable habitat model (see sections 4.1.2 Habitat Resiliency Factors and 8 Appendix). Although the previous modeling efforts were not directly included in this SSAs analysis, they can be further expanded upon or considered in future salamander SSA updates, conservation planning, or modeling efforts.

Table 3.1. Summary of Geographic Units, Subunits, and current/historical Jemez Mountains Salamander Occupancy.

Unit Name	Unit Area (Acres)	Unit Land Ownership	Earliest Decade of Salamander Detection	Most Recent Contemporary Salamander Detections	Total Number of Subunits	Number of Subunits Historically Occupied	Number of Subunits Currently Occupied	Percent Currently Occupied
Forest West	62,000	U.S. Department of Agriculture (Santa Fe National Forest; Cuba and Jemez Ranger Districts)	1960s	2022	7	5	5	71
Preserve	68,000	U.S. Department of Interior (National Park Service; Valles Caldera National Preserve)	1950s	2022	7	7	2	29
Monument	60,000	U.S. Department of Agriculture (Santa Fe National Forest; Jemez Ranger District) and U.S. Department of Interior (National Park Service; Bandelier National Monument)	1950s	2022	7	6	5	71
Laboratory	42,000	U.S. Department of Agriculture (Santa Fe National Forest; Espanola Ranger District) and U.S. Department of Energy (Los Alamos National Laboratory)	1950s	2019	6	6	5	83
Forest North	59,000	U.S. Department of Agriculture (Santa Fe National Forest; Coyote and Espanola Ranger Districts)	1970s	2014	7	4	1	14

4 CURRENT CONDITION

This chapter analyzes the demographic and habitat conditions needed to maintain population resiliency and species' redundancy and representation. For this assessment, viability is defined as the ability of the species to sustain occupancy in subunits in the wild over time. Using the SSA framework, we describe species' viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation.

4.1 Population Resiliency

For the Jemez Mountains salamander to maintain viability, its populations (subunits used as a surrogate for populations for these analyses), or some portion thereof, must be resilient; that is, they must be able to withstand stochastic events arising from spatially- or temporally occurring random factors. Stochastic events that have the potential to affect Jemez Mountains salamander subunits may include drought, wildfire, insect outbreaks, and erosion.

Demographic factors such as recruitment influence the viability of Jemez Mountains salamander subunits. Recruitment potential is influenced by habitat elements that determine whether Jemez Mountains salamander subunits can grow to carrying capacity, thus increasing resiliency. A resilient Jemez Mountains salamander subunit needs sufficient habitat with diverse food resources to support reproduction and survival. These relationships are shown in Figure 4.1.

To assess the current and possible future conditions of Jemez Mountains salamander subunits, we focused on factors that influence the populations and those for which we have sufficient data. To assess the current resiliency of the 34 subunits of Jemez Mountains salamanders, we quantified the demographic and habitat factors described in the population resiliency factors section 4.1.1 Population resiliency factors. These factors include recruitment, favorable habitat, and burn. These are discussed in more detail in section 4.1.1 Population resiliency factors (Table 4.1) and section 4.1.2 Habitat resiliency factors (Table 4.2 and 4.3). Using these three factors, we created the condition category definitions in Table 4.4, to which we then assigned a category of high, moderate, or low condition for each factor within each subunit. Finally, we assessed the current overall condition of each subunit based on its average condition category across these demographic and habitat factors, with all factors weighed equally.

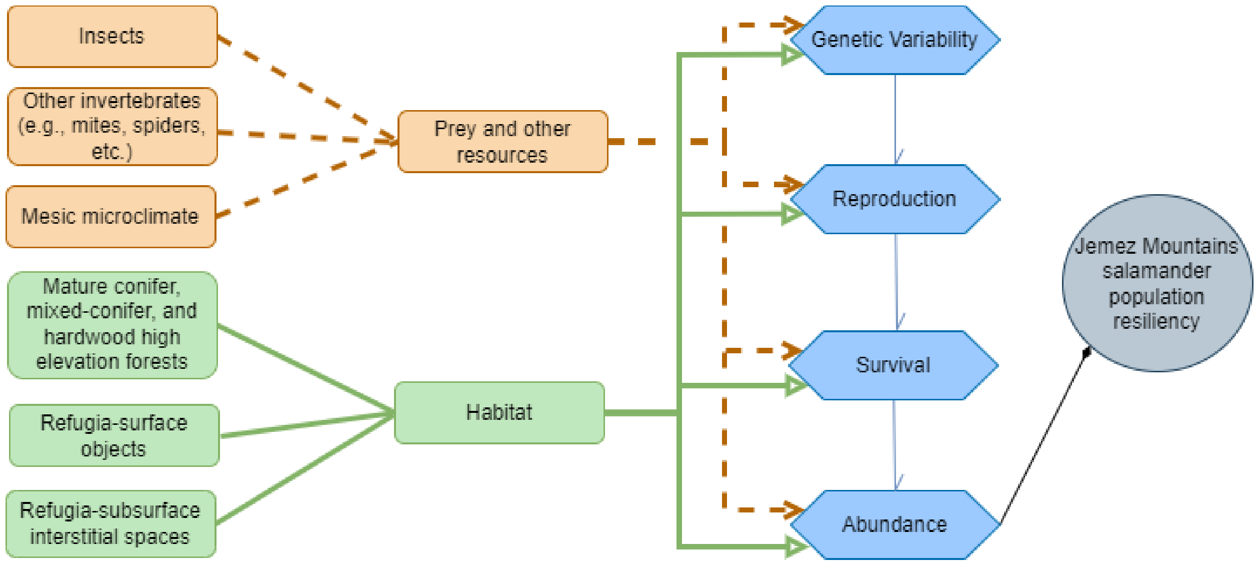

Figure 4.1. Jemez Mountains salamander population ecology.

4.1.1 Population resiliency factors

Recruitment

Recruitment includes the processes by which individuals are added to populations, including birth, maturation, emigration, and immigration. Recruitment must occur for populations to be resilient to stochastic events. In this SSA, we evaluated salamander recruitment in two ways: through direct observation and inference. We can differentiate adult and juvenile salamanders through morphological assessment of SVL during surveys. If a juvenile is detected, the direct observation provides evidence that recruitment is occurring. We infer recruitment is occurring in two ways. First, we assume that if multiple adult salamanders are located close together in space and time that it is possible for them to interact and breed. Second, if an area with historical detection(s) also includes a detection within the last 15 years (which should capture the estimated lifespan of the salamander), this documents persistence over time and indicates recruitment is occurring. Because a salamander was documented moving 43.3 ft (13.2 m) in four days (N. Karraker, pers. comm.), it is reasonable to assume that salamanders are capable of dispersing further (or similar) distances across suitable habitat over a longer timeframe. Ramotnik (1988, p. 28) documented a Jemez Mountains salamander moving a total non-linear distance of 144 ft (43.9 m) over 22 days. We chose this maximum distance (43.9 m) to buffer salamander detections and identify where buffered salamander detections overlapped as it is possible a salamander could move this distance through suitable habitat. These areas of overlap and direct observations of juvenile salamanders are defined as “locations” for the purposes of evaluating recruitment in this SSA. All mapping and geoprocessing were conducted in ArcGIS Pro 2.9.4. Additional research is needed to better understand Jemez Mountains salamander movements and dispersal capabilities.

For a location to contribute to a subunit’s recruitment condition, it must meet at least one of the requirements outlined in Table 4.1.

Table 4.1. Jemez Mountains salamander requirements for a location to contribute to a subunit's condition for the recruitment population resiliency factor. Salamander detections can be either one salamander observed during a survey or multiple salamanders observed during a survey.

Location Requirement	Contributes to the following condition categories
1. Location is comprised of multiple salamander detections documented over the last 10 years.	High, Moderate, Low
2. Location is comprised of one salamander detection in the last 10 years and at least one detection >10 years old.	High, Moderate, Low
3. Location is comprised of at least one juvenile/subadult detection in the last 10 years	High, Moderate, Low
4. Location is comprised of multiple salamander detections occurring >10 but ≤ 15 years ago.	Moderate, Low
5. Location is comprised of one salamander detection in the last 15 years and at least one detection >15 years old.	Moderate, Low
6. Location is comprised of at least one juvenile/subadult detection in the last 15 years	Moderate, Low
7. Location is comprised of multiple salamander detections occurring >15 but ≤ 20 years ago.	Low
8. Location is comprised of at least two juvenile/subadult detections in the last 20 years	Low

For recruitment, condition category definitions are based on the number of salamander locations that meet specific requirements. Because more recent detections provide greater confidence that the subunit is still presently occupied, we incorporated timeframes of 10 years, 15 years, and 20 years into requirements associated with locations (Table 4.1) when defining high, moderate, and low condition for recruitment. These timeframes were considered appropriate since they overlap with the salamander's assumed lifespan. We define high condition as a subunit with three or more locations that meet a location requirement for high (Table 4.1 and Table 4.4), moderate condition as a subunit with at least two locations that meet a requirement for moderate (Table 4.1 and Table 4.4), and low condition as a subunit with at least one location that meets a requirement for low (Table 4.1 and Table 4.4). We define very low/unknown condition as a subunit with no locations that meet location requirements in Table 4.1 or there is no known survey effort (Table 4.4). It is important to note that the final recruitment condition of the subunit will be determined by the highest qualifying condition category definition. For example, if a subunit has four locations, two that meet requirements four and five and two that meet requirements one and two (Table 4.1) the highest recruitment condition for the subunit is moderate. All four locations meet the requirements for moderate and low, but only two meet the requirements for high and thus, the minimum number of locations (three) needed for high recruitment condition are not met.

4.1.2 Habitat resiliency factors

Favorable Habitat

Jemez Mountains salamander habitat must contain the on-the-ground conditions necessary for Jemez Mountains salamander to breed, feed, and shelter (Figure 4.1). Because necessary data that would allow for the evaluation of microhabitat conditions important to the salamander, such as air and soil temperatures, relative humidity, precipitation, coarse woody debris, and food items, are not comprehensively available, we evaluated potential habitat using macrohabitat elements that directly or indirectly provide the microhabitat used by the salamander. Jemez Mountains salamanders are known to occur in forests consisting of white fir, Rocky Mountain maple, Engelmann spruce, blue spruce, Ponderosa pine, quaking aspen, and Douglas fir (Reagan 1972, p. 487). Ecological factors, such as forest composition and successional stage, and disturbance-related factors, including fire scale, magnitude, and return intervals and forest management activities, influence the amount of coarse woody debris in forests (Graham et al. 1994, p. 1). A closely related salamander species in California was more abundant and exhibited higher body condition in less disturbed forests with higher canopy cover and higher downed wood volume (e.g., Karraker and Welsh 2006, p. 136). Larger trees in undisturbed forests contribute higher quantities of downed wood of larger size (Bunnell and Houde 2010, pp. 407-408), which are more resistant to degradation and are thus longer-lived. The recruitment and retention of larger-size downed wood is particularly important for species reliant on this habitat component in disturbance-prone landscapes, such as the Jemez Mountains. At least 23 species of terrestrial salamanders have exhibited population declines or extirpations associated with losses of downed wood attributable to disturbance (reviewed in Means et al. 1996, p. 426). To understand and identify habitat within the analysis area that is likely to contain the microhabitat elements needed by the salamander, we included forest type, tree density, and vegetation height in a geospatial forest model (section 8 Appendix). Based on feedback from species experts on the SSA core team, we assumed that microhabitat elements are more strongly correlated with higher elevation, mesic mixed-conifer forests than lower elevation, ponderosa pine forests and positively correlated with increasing tree density and height. Data from the forest model was ranked into habitat described as favorable, moderately favorable, less favorable, and non-habitat to reflect the probability of the modeled habitat containing the necessary microhabitat elements needed to support breeding, feeding, and sheltering.

Jemez Mountains salamanders are known to occupy the modeled habitat types of favorable, moderately favorable, and less favorable. Favorable habitat has the highest probability of having proper forest conditions, based on the highest value of the data inputs from the forest model and in general can be described as mature, mixed-conifer and spruce-fir forest (section 8 Appendix). Moderately favorable has a good probability of having proper forest conditions, based on higher mixed values of the data inputs from the forest model and in general can be described as mature ponderosa pine and mid-mature, mixed-conifer forest (mesic and dry-mesic) (section 8 Appendix). Less favorable habitat has a lower probability of having proper forest conditions, based on lower values of the data inputs from the forest model and in general can be described as mid-mature ponderosa pine and young to mid-mature mixed-conifer forest (mesic and dry-mesic, respectively) (section 8 Appendix). In the SSA, we refer to these three habitat types as potential salamander habitat. Of potential salamander habitat, favorable habitat has the greatest potential of maintaining micro-habitat conditions needed for salamander persistence. Therefore, in our assessment of current and future condition, we evaluated how much of a subunit's potential habitat is ranked as favorable habitat.

After reviewing the data from the forest model, the SSA core team determined percentage cut-off amounts (through discussion and by relying on expert knowledge) for high, moderate, and low condition within favorable habitat. For favorable habitat, we defined high condition as a subunit with ≥ 20 percent of potential salamander habitat ranked as favorable, moderate condition as a subunit with ≥15 percent <20 percent of potential salamander habitat ranked as favorable, low condition as a subunit with ≥10 percent <15 percent of potential salamander habitat ranked as favorable, and very low condition as a subunit with <10 percent of potential salamander habitat ranked as favorable (Table 4.4).

Burn

As a narrowly distributed species endemic to the Jemez Mountains, the Jemez Mountains salamander is likely adapted to historical fire regimes. Historically, pure ponderosa pine forests comprised a greater proportion of the Jemez Mountains, and more mesic mixed-conifer forests were not as continuous or expansive as found today (Margolis and Malevich 2016, p. 14; Margolis et al. 2017, p. 435). Ponderosa pine stands burn more frequently and with lower severity than more mesic mixed-conifer forests, which have a longer fire return interval but typically burn at higher severity than ponderosa pine forests (Touchan et al. 1996, pp. 41-42). Given the historical landscape and the species' habitat preferences, we assume that Jemez Mountains salamanders are better adapted to fire regimes characteristic of Ponderosa pine and mesic, mixed-conifer forests (i.e., low-severity, large scale fires and low- to moderate-severity fires of smaller scale fires with localized high-severity impacts, respectively). These fire regimes, however, have been altered by past forest management practices and changes in forest composition, which may differentially impact the salamander and its habitat. The policy of fire suppression was widespread throughout the western U.S., and there is strong evidence suggesting that these activities have resulted in increased fuel loads, which appear responsible for the increase in size and intensity of wildfires (Arno and Brown 1991, pp. 40-42; Arno et al. 2000, pp. 226-229; Calkin et al. 2005, p. 182). A century of fire suppression in California in fuel-limited systems such as pine and mixed-conifer and Douglas fir resulted in increased rates of high-intensity and -severity burning (Steel et al. 2015, pp. 12-15). Because wildfires have increased in frequency, size, and severity from historical norms, we assume that Jemez Mountains salamander populations are experiencing declines through direct mortality during fires and indirect mortality associated with post-fire habitat loss and degradation and/or reductions in abundances or changes in the composition of food resources.

The SSA core team identified the need to quantify the potential impacts of contemporary fire regimes on Jemez Mountains salamanders, based on our current understanding and available information. We developed a salamander fire vulnerability index related to fire severities (wildfire and prescribed). We provide the habitat impacts considered to be associated with fire severity in the context of impacts to the Jemez Mountains salamander (Table 4.2) and a summary of life events affected by the impact of fire on habitats (Table 4.3). For low- to moderate-severity wildfires, we assumed greater impacts to surface cover refugia and organic materials during the dry season (typically fall through spring) which would impact breeding, feeding, and sheltering of the salamander during the subsequent monsoon season. For moderate-severity wildfires, we assumed that impacted habitat remains viable for salamander biological functions, but that as loss of salamander habitat and food resources (Gibson et al. 2022, pp. 5-6) occurs, salamanders may experience impacts from increased fragmentation (which could include unsuitable habitat areas between suitable habitat areas), and degradation in the quantity and quality of cover objects and organic materials. For high-severity and ground-smoldering wildfires, we assumed that there is an increased loss of moisture in soils and in remaining vegetation (live or dead) immediately and over time, potentially resulting in an uninhabitable environment for the species, and that smoldering ground fire can result in direct mortality even when salamanders are below ground during the dry season. In addition, as fire severity increases, the amount and depth that heat penetrates underground can increase. It is important to note that because fire severity is evaluated via averaged ground reflectance in 30-m grids (U.S. Geological Survey [USGS] Burn Area Reflective Classification [BAER] database accessed May 2023), ground-smoldering fire which occurs in areas quantified as low- or moderate-severity burns cannot be detected but likely only have small-scale localized impacts within those quantified areas. The greatest concern is associated with ground-smoldering fires that are larger in scale and can result in substantial habitat loss or fragmentation. Such fires are more likely to occur in areas with high levels of ground fuel resulting from previous fire impacts, blow-down from severe wind events, or fuel treatments from past management regimes. Fire severities are defined in the USGS BAER database (accessed May 2023).

Although fire can impact the species negatively, fire can also have positive short-term impacts such as increased decay of current cover objects, and positive long-term impacts such as increased woody object retention and reduction in midstory vegetation which allows for pine/fir regrowth. These impacts are not included in the table below but are considered in overall changes to habitat from wildfires in future conditions.

Table 4.2. Habitat impacts considered associated with fire severities.

Low Severity	**Moderate Severity**	**High Severity or Ground Smoldering**
• Jemez Mountains salamander habitat remains suitable • <30% canopy cover loss • Soils are not impacted	• Impacts to some or all the following: canopy cover, surface refugia, soils, and organic materials but soils and canopy are less impacted • 30-70% loss of canopy, surface refugia, and organic materials are realized • Soils are moderately penetrated by heat	• Crown or surface fires, alone or in concert • >70% loss of canopy, surface refugia, and organic materials • Soils experience deep penetration by heat associated with smoldering ground fire

Table 4.3. Jemez Mountains salamander life events affected by fire impacts to habitat.

Fire Impact	Life Event Affected
Loss of Canopy	Breeding, Feeding, Sheltering
Loss of Cover Objects	Breeding, Feeding, Sheltering
Heat Penetration Depth	Feeding, Sheltering
Loss of Organic Materials	Breeding, Feeding, Sheltering

To assess the impact of wildfire across the potential habitat of the Jemez Mountains salamander, we evaluated each subunit for fire severities assumed to negatively impact the species. We quantified the percent of the subunit which has been impacted by moderate- to high-severity fire, the proportion of which was severely burned, and any direct impacts of moderate- to high-severity burns on salamander detections over the last 14 years (from 2008-2021; section 8 Appendix). We assumed equal distribution of salamanders across potential habitat; that low-severity fires have minimal to no impacts to canopy cover, surface refugia, soils, or other organic materials; and that any degradation from low-severity fires is minimal, such that limited direct or indirect impacts to salamanders are expected to occur. For burn, we defined high condition as a subunit that is currently < 20 percent burned by moderate to high-severity fire and no more than 10 percent of which is impacted by high-severity fire. In addition, moderate- to high-severity fires will not have occurred in areas where salamanders have been detected in the last 14 years (from 2008-2021). Moderate condition is defined as a subunit that is >20 percent but < 40 percent burned by moderate- to high-severity fire and no more than 20 percent of which is impacted by high-severity fire. In addition, moderate- to high-severity fire may have impacted < 30 percent of areas where salamanders have been detected in the last 14 years (from 2008-2021). We defined low condition as a subunit that is > 40 percent but < 90 percent burned by moderate- to high-severity fire; > 20 percent and < 70 percent of which has been impacted by high-severity fire. In addition, moderate- to high-severity fire may have impacted > 30 percent and < 90 percent of areas where salamanders have been detected in the last 14 years (from 2008-2021). Lastly, we defined very low condition as a subunit that is > 90 percent burned by moderate- to high-severity fire and no less than 70 percent of which has been impacted by high-severity fire. In addition, moderate- to high-severity fire may have impacted > 90 percent of areas where salamanders have been detected in the last 14 years (from 2008-2021; Table 4.4).

Table 4.4. Definitions of condition categories used to assess demographic and habitat factors for current population conditions and projected future conditions. Note, “Very low/Unknown” applies only to Recruitment condition due to lack of historical systematic surveys. For the Favorable Habitat and Burn factors, “Very low” is used for assessments of condition.

Condition Category	Recruitment	Favorable Habitat	Burn
High	Three or more locations within a subunit. Reference Table 4.1 for location requirements.	≥ 20% of potential salamander habitat is ranked as favorable.	< 20% of subunit is burned by moderate to high-severity fire, no more than 10% of which is impacted by high-severity fire. Moderate to high-severity fire has not impacted areas with salamander detections over the last 14 years (from 2008-2021).
Moderate	Two or more locations within a subunit. Reference Table 4.1 for location requirements.	≥15% <20% of potential salamander habitat is ranked as favorable.	>20% and < 40% of subunit is burned by moderate to high-severity fire, no more than 20% of which is impacted by high-severity fire. Moderate to high-severity fire has impacted < 30% of areas with salamander detections over the last 14 years (from 2008-2021).
Low	One or more locations within a subunit. Reference Table 4.1 for location requirements.	≥10% <15% of potential salamander habitat is ranked as favorable.	> 40% and < 90% of subunit is burned by moderate to high-severity fire, > 20% and < 70% of which is impacted by high-severity fire. Moderate to high-severity fire has impacted > 30% and < 90% of areas with salamander detections over the last 14 years (from 2008-2021).
Very low/ Unknown	No known survey efforts, or detections or locations do not meet the requirements outlined in Table 4.1.	<10% of potential salamander habitat is ranked as favorable.	> 90% of subunit is burned by moderate to high-severity fire, no less than 70% of which is impacted by high-severity fire. Moderate to high-severity fire has impacted > 90% of areas with salamander detections over the last 14 years (from 2008-2021).

Table 4.5. Habitat metrics including acres of favorable, moderately favorable, and total potential habitat, and percent favorable habitat (of total potential habitat) for each Jemez Mountains salamander subunit. Data layers used to generate this table are discussed in section 8.10 Current Condition: Wildfire Vulnerability Model.

Unit:subunit	Favorable Habitat	Moderately Favorable Habitat	Total Potential Habitat	% Favorable
Forest North:1	1436	2601	10217	14.1%
Forest North:2	548	1197	4872	11.3%
Forest North:3	162	470	3541	4.6%
Forest North:4	1353	1840	7106	19.0%
Forest North:5	907	1393	4698	19.3%
Forest North:6	955	1720	6344	15.1%
Forest North:7	802	987	3418	23.5%
Laboratory:1	75	201	1838	4.1%
Laboratory:2	396	648	2906	13.6%
Laboratory:3	8	165	1412	0.5%
Laboratory:4	52	151	1077	4.8%
Laboratory:5	191	362	1925	9.9%
Laboratory:6	53	99	1302	4.0%
Monument:1	980	1488	7716	12.7%
Monument:2	181	257	1675	10.8%
Monument:3	33	103	891	3.7%
Monument:4	47	127	1335	3.5%
Monument:5	10	57	3053	0.3%
Monument:6	82	196	3000	2.7%
Monument:7	703	1684	6528	10.8%
Forest West:1	2734	3079	10770	25.4%
Forest West:2	1740	1975	6804	25.6%
Forest West:3	956	2357	9977	9.6%
Forest West:4	1389	1713	6360	21.8%
Forest West:5	366	1406	8150	4.5%
Forest West:6	199	613	3556	5.6%
Forest West:7	610	1069	4371	13.9%
Preserve:1	777	1148	4301	18.1%
Preserve:2	1604	1877	7056	22.7%
Preserve:3	528	926	4655	11.3%
Preserve:4	1073	321	3140	34.2%
Preserve:5	8	1365	4608	0.2%
Preserve:6	441	823	4148	10.6%
Preserve:7	189	986	4971	3.8%

Table 4.6. Burn metrics including moderate and severe burned acreage, total acreage, percent of moderate and severe burned, percent of severe burned for Jemez Mountains salamander subunits.

Unit:subunit	Acres of Moderate and Severe Burned	Total Subunit acres	% Moderate and Severe Burned	% Severe Burned
Forest North:1	0	15113	0.0%	0.0%
Forest North:2	912	9096	10.0%	3.2%
Forest North:3	1096	6429	17.0%	2.1%
Forest North:4	914	10694	8.5%	3.3%
Forest North:5	31	6022	0.5%	0.2%
Forest North:6	0	7198	0.0%	0.0%
Forest North:7	0	4435	0.0%	0.0%
Laboratory:1	4994	7847	63.6%	43.3%
Laboratory:2	3994	8887	44.9%	21.8%
Laboratory:3	686	6641	10.3%	0.3%
Laboratory:4	2938	6704	43.8%	29.7%
Laboratory:5	2040	5675	36.0%	22.6%
Laboratory:6	4985	6055	82.3%	64.5%
Monument:1	4509	11888	37.9%	14.6%
Monument:2	2475	5981	41.4%	18.7%
Monument:3	1708	4783	35.7%	18.1%
Monument:4	3130	4958	63.1%	35.6%
Monument:5	13523	15982	84.6%	46.7%
Monument:6	7438	8557	86.9%	46.4%
Monument:7	1973	8276	23.8%	5.7%
Forest West:1	0	12639	0.0%	0.0%
Forest West:2	0	8228	0.0%	0.0%
Forest West:3	168	11657	1.4%	0.2%
Forest West:4	0	7203	0.0%	0.0%
Forest West:5	366	10521	3.5%	1.4%
Forest West:6	2274	6625	34.3%	20.5%
Forest West:7	0	5093	0.0%	0.0%
Preserve:1	766	11108	6.9%	1.1%
Preserve:2	0	9001	0.0%	0.0%
Preserve:3	1404	7854	17.9%	1.9%
Preserve:4	7898	14327	55.1%	28.4%
Preserve:5	594	9232	6.4%	0.8%
Preserve:6	3397	10616	32.0%	2.9%
Preserve:7	12	6587	0.2%	0.0%

4.2 Current Resiliency

Resiliency describes the ability of populations to withstand stochastic events. We can measure resiliency based on metrics of population health. Highly resilient populations are better able to withstand disturbances such as random fluctuations in birth rates (demographic stochasticity), variation in rainfall (environmental stochasticity), or the effects of anthropogenic activities. Small populations distributed over a limited range, like those of the Jemez Mountains salamander, are limited in their ability to rebound from stochastic events. For this SSA, favorable habitat, recruitment, and burn categories in each subunit were used to help provide a measure of resiliency across the salamander's current range.

Based on the favorable habitat, recruitment, and burn categories in each subunit, the overall resiliency is as follows: Forest North subunits range from Moderate to Low, Forest West subunits range from High to Very Low/Unknown, Laboratory subunits are all in Low, Monument subunits range from Low to Very Low/Unknown, and Preserve subunits range from Moderate to Low (Table 4.7). Conditions of each resiliency factor are provided in Table 4.7. A visual representation of subunit resiliency is provided in Figure 4.2.

Table 4.7. Current resiliency conditions of Jemez Mountains salamander subunits.

Unit:subunit	Recruitment	Favorable Habitat	Burn	Overall Condition
Forest North:1	Very Low/Unknown	Low	High	Low
Forest North:2	Very Low/Unknown	Low	High	Low
Forest North:3	Very Low/Unknown	Very Low	High	Low
Forest North:4	Very Low/Unknown	Moderate	High	Moderate
Forest North:5	Very Low/Unknown	Moderate	High	Moderate
Forest North:6	Very Low/Unknown	Moderate	High	Moderate
Forest North:7	Very Low/Unknown	High	High	Moderate
Laboratory:1	Moderate	Very Low	Low	Low
Laboratory:2	Moderate	Low	Low	Low
Laboratory:3	Low	Very Low	High	Low
Laboratory:4	Moderate	Very Low	Low	Low
Laboratory:5	Low	Very Low	Low	Low
Laboratory:6	Low	Very Low	Low	Low
Monument:1	Low	Low	Low	Low
Monument:2	Very Low/Unknown	Low	Very Low	Very Low/Unknown
Monument:3	Very Low/Unknown	Very Low	Moderate	Low
Monument:4	Moderate	Very Low	Low	Low
Monument:5	Moderate	Very Low	Low	Low
Monument:6	Very Low/Unknown	Very Low	Low	Very Low/Unknown
Monument:7	Very Low/Unknown	Low	Moderate	Low
Forest West:1	Moderate	High	High	High
Forest West:2	High	High	High	High
Forest West:3	Low	Very Low	High	Low
Forest West:4	Very Low/Unknown	High	High	Moderate
Forest West:5	Very Low/Unknown	Very Low	High	Low
Forest West:6	Very Low/Unknown	Very Low	Low	Very Low/Unknown
Forest West:7	High	Low	High	Moderate
Preserve:1	Low	Moderate	High	Moderate
Preserve:2	Very Low/Unknown	High	High	Moderate
Preserve:3	High	Low	High	Moderate
Preserve:4	Very Low/Unknown	High	Low	Low
Preserve:5	Very Low/Unknown	Very Low	High	Low
Preserve:6	Very Low/Unknown	Low	Moderate	Low
Preserve:7	Very Low/Unknown	Very Low	High	Low

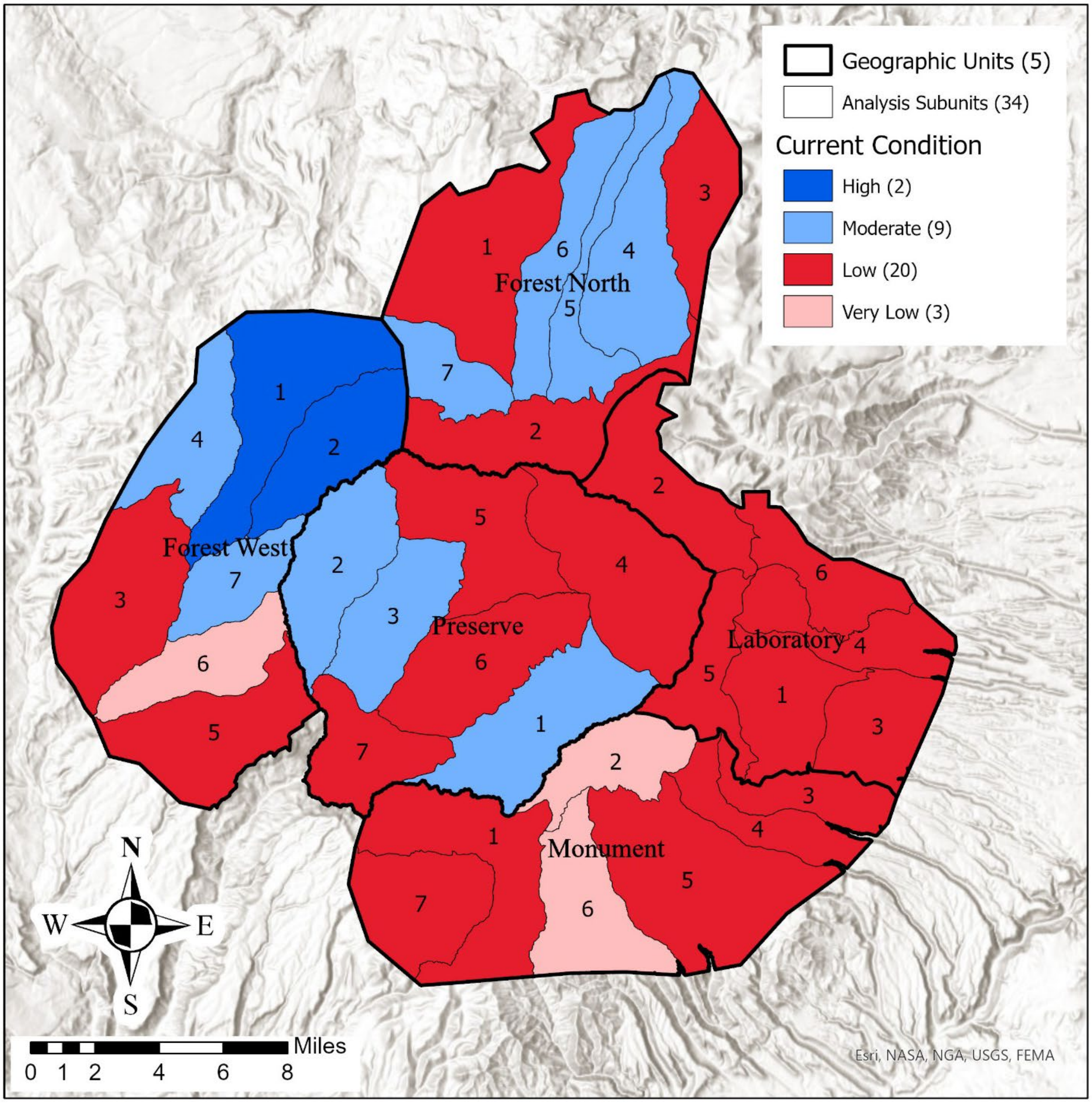

Figure 4.2. Overall resiliency condition of Jemez Mountains salamander subunits within the range of the species in the Jemez Mountains in northern New Mexico based on favorable habitat, recruitment, and burn condition categories discussed in the Jemez Mountains salamander Species Status Assessment.

4.3 Current Redundancy

Redundancy refers to the number of populations of a species and their distribution across the landscape, reflecting the ability of a species to survive catastrophic events. The greater the number of populations/subpopulations, and the more widely they are distributed, the lower the likelihood a single catastrophic event will cause a species to become extinct. Species that are well distributed across their historical range are considered less susceptible to extinction and more likely to be viable than species that are confined to small portions of their historical ranges (Carroll et al. 2010, entire; Redford et al. 2011, p. 40).

The Jemez Mountains salamander is a narrow endemic with a naturally limited range. Historically, the salamander occurred predominantly above approximately 2,220 m in mixed-conifer forests in portions of three counties in New Mexico. In this SSA, we assessed resiliency of subunits based on recruitment, favorable habitat, and wildfire and determined that current resiliency is high or moderate in 11 out of 34 subunits (Figure 4.2). Not all subunits in overall high or moderate condition are in moderate or high condition for recruitment; four (Forest West 1, 2, 7 and Preserve 3) are in moderate or high recruitment condition while seven (Forest North 4, 5, 6, 7, Forest West 4, and Preserve 1 and 2) are in low or very low/unknown recruitment condition (Table 4.7). Therefore, it is also important to consider a subunit's recruitment condition to understand current redundancy. Currently, 9 of 34 subunits are in high or moderate recruitment condition, indicating Jemez Mountains salamander persistence in those 9 subunits over time and within the last 10 to 15 years (Figure 4.3). Of these, Forest West 1, 2, 7, and Preserve 3 have moderate to high habitat conditions but Laboratory 1, 2, and 4, and Monument 4 and 5, have poor habitat conditions, indicating that salamanders in these 5 subunits are at risk if additional habitat degradation or loss occurs. Seven of the 26 subunits currently in low or very low recruitment condition have good habitat conditions, suggesting a high likelihood of detecting salamanders if survey effort is increased in Forest North 4, 5, 6, 7, Forest West 4, and Preserve 1 and 2. We note that Forest North 7 and Forest West 4 are not known to be historically occupied. Because 25 of 34 subunits have low or very low recruitment condition, we consider current redundancy to be poor for the Jemez Mountains salamander. Increasing survey efforts in the same locations within some of the low or very low subunits (for recruitment condition) may help clarify redundancy in future SSA updates.

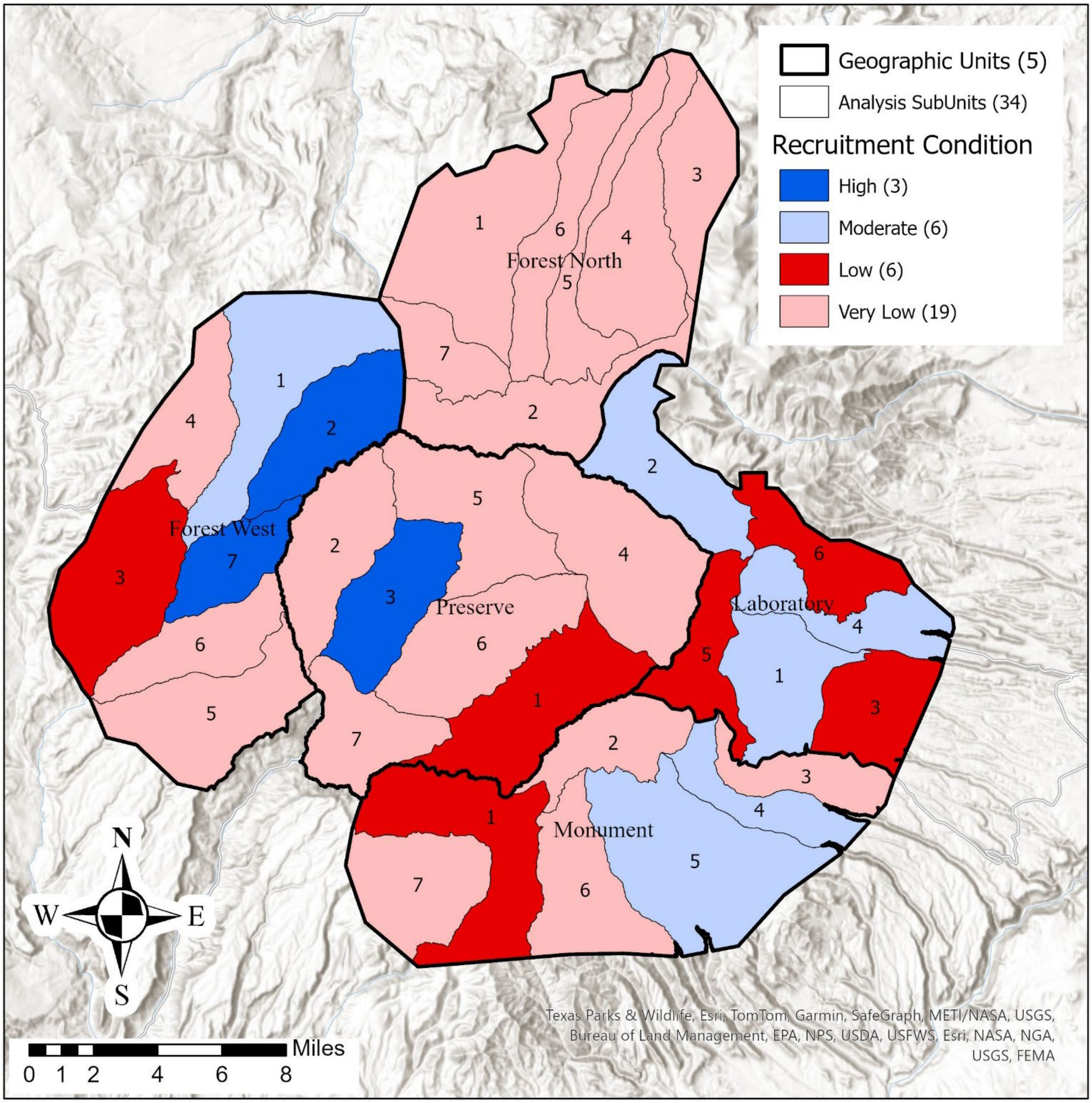

Figure 4.3. Current recruitment condition of Jemez Mountains salamanders.

4.4 Current Representation

Representation refers to the breadth of genetic or ecological diversity within a species and reflects the ability of a species to adapt to changing environmental conditions. The greater the diversity, the more successfully a species should be able to respond to changing environmental conditions. Representation in the form of genetic or ecological diversity is important in maintaining the capacity of Jemez Mountains salamanders to adapt to environmental changes.

The Jemez Mountains salamander is a narrow endemic found only in the Jemez Mountains in New Mexico; thus, the breadth of ecological diversity for the species is limited to ponderosa pine dominated, mixed-conifer (dry and mesic), and subalpine spruce-fir forests. Historically, these forest types and their distribution were shaped across the landscape by climate, influenced locally by topography, and sustained through wildfire. While increasing temperatures and drought conditions likely influence salamander persistence at lower elevations, altered fire regimes, influenced by climate and forest management practices, have altered the forest (composition, structure, and fuel load) available for salamanders, further limiting ecological diversity. Additionally, Wiltenmuth (1997, entire) found that the Jemez Mountains salamander was seemingly better adapted to a drier climate than other *Plethodon* species, such that they should be better adapted to changes in climatic conditions (e.g., rising temperatures); however, any changes may outpace the species' adaptative capacity. Specific information on the species' historical or current genetic diversity is lacking. However, information suggestive of density and the distribution of areas with recruitment may provide insight into potential changes in genetic diversity over time.

Based on our current assessment, 56 percent of salamander subunits (19 out of 34) are in very low/unknown recruitment condition, and 18 percent (6 out of 34) are in low recruitment condition (Table 4.7), Figure 4.3). Together, over 74 percent of subunits (25 out of 34) have locations comprised of multiple salamander detections occurring > 15 but < 20 years ago, locations with detections > 20 years old, or no salamander detections. Twenty six percent (9 out of 34) of salamander subunits are moderate or high recruitment condition. Salamanders, however, have been reliably detected in the same locations only within three subunits (Forest West 2 and 7; and Preserve 3) since 2018. These subunits, within two of five Geographic Units (Forest West and Preserve), are considered species strongholds or hot spots with reliable recruitment. Although survey effort has varied over time, evaluation of historical and current salamander detections during survey efforts suggests that salamander densities and their distribution have decreased over time (see chapter 3 DISTRIBUTION, above). Such declines have likely resulted in the loss of genetic diversity. Based on this information, combined with the fact that the salamander spends a large portion of its life underground (making it difficult to survey for and find), we rate the Jemez Mountains salamander currently as having poor representation across its range. Increasing survey efforts in the same locations within some of the low or very low subunits (for recruitment) may help clarify representation in future SSA updates.

5 STRESSORS ON JEMEZ MOUNTAINS SALAMANDER VIABILITY

In this chapter, we evaluate the current and future stressors that affect the Jemez Mountains salamander needs for long-term viability (i.e., the Jemez Mountain salamander's ability to sustain occupancy in subunits in the wild over time). We focus on the current and future stressors rather than providing a comprehensive overview of all past factors that contributed to the species' historical declines. Additional information on factors contributing to the species' status can be found in the listing rule (USFWS 2013a; entire). Current and potential future stressors, along with current and future expected distribution and abundance, determine viability, and, therefore, vulnerability to extinction. Below we discuss the stressors and stressor sources that would have important impacts on the future viability of Jemez Mountains salamander subunits, as well as potential stressors that were not carried forward into our analysis due to lack of evidence or because the stressor is predicted to have minimal impacts.

5.1 Environmental Changes

Environmental changes directly and indirectly impact the ecosystems that Jemez Mountains salamanders depend on throughout their life cycle. These changes drive numerous stressors that negatively impact the resources and conditions needed by Jemez Mountains salamanders, thereby impacting the species' demographic attributes (e.g., female reproductive success, juvenile survival, adult and subadult survival) and viability. Below, we discuss stressors related to changes in environmental conditions, including drought (warming temperatures and decreases in precipitation and accumulated snowpack) and wildfire. We did not carry forward the stressors erosion or insect/tree disease as they relate to environmental changes into our analyses of future condition. See section 5.3 Environmental and Human Development Stressors Not Included in Future Viability Analysis for more information on erosion and insect damage/tree disease. Figure 5.1 below provides an overview of how environmental changes relate to these stressors, resources/habitat needed for the Jemez Mountains salamander, demographics, and, ultimately, viability.

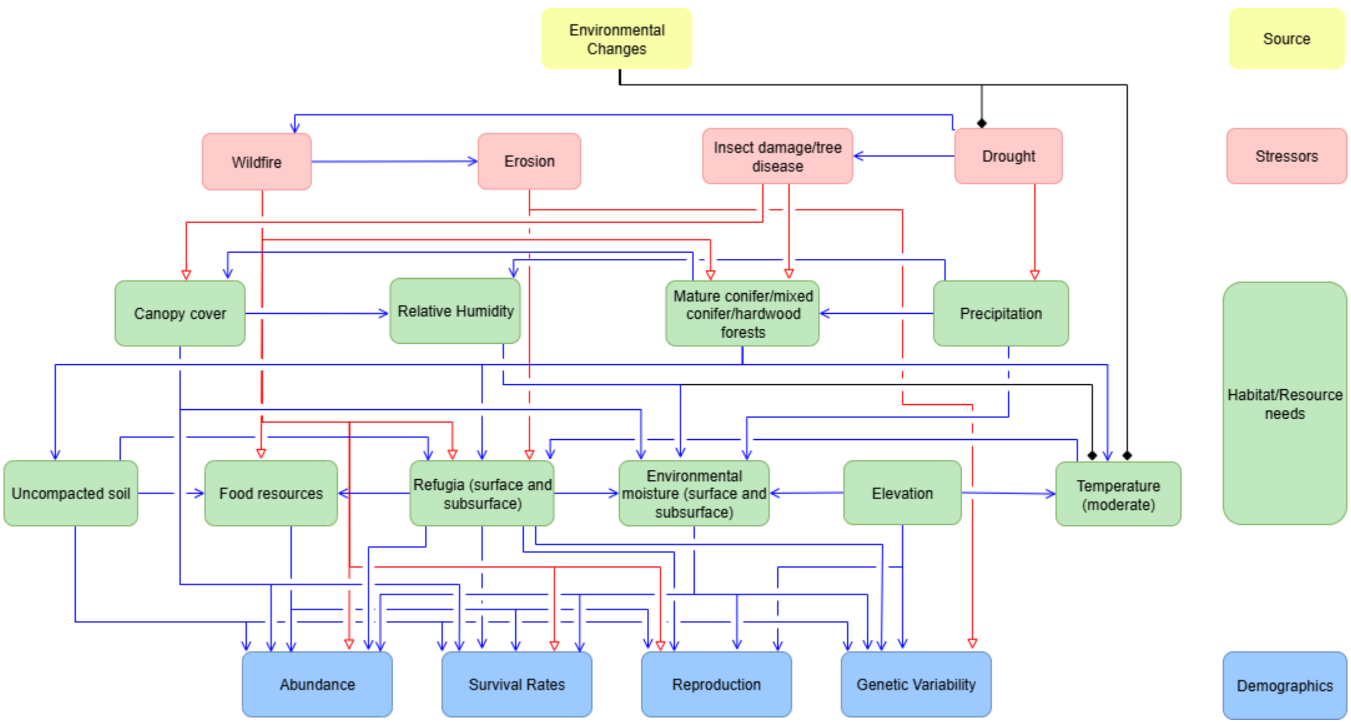

Figure 5.1. Conceptual model developed by the SSA Core Team illustrating the relationship between environmental changes and resulting stressors to both habitat and resources vital to Jemez Mountains salamander viability. These relationships are discussed throughout this chapter. Note that arrow colors correspond to positive (blue, line arrow) or negative (red, hollow arrow) relationships; a black arrow, closed diamond, indicates that the relationship may be either positive or negative.

Drought

The southwestern U.S. has been and is expected to get hotter and drier into the future (Seager et al. 2007, entire; Gonzalez et al. 2018, pp. 1108-1114). The southwestern U.S. is currently experiencing long-term drought, and the trend is predicted to continue with impacts that are observable and likely to worsen. These changes would have profound effects on the amount, permanence, and quality of habitat for Jemez Mountains salamanders. From 2000 to 2020, average temperatures in northern New Mexico have differed from the long-term average by an increase of approximately 0.8 degrees Celsius (°C; approximately 1.4 to 1.6 degrees Fahrenheit [°F]), and the region has been abnormally dry, experiencing increased moderate to severe drought conditions (U.S. Environmental Protection Agency [EPA] 2021, accessed May 11, 2023). Drought conditions in and around the Jemez Mountains as of May 2023 were categorized as abnormally dry and/or moderate drought, which represent low to mid-level categories describing drought intensity, with conditions worsening into 2024 (National Oceanic and Atmospheric Administration 2023, entire).

Climate simulations of the Palmer Drought Severity Index (PDSI) (a calculation of the cumulative effects of precipitation and temperature on surface moisture balance) for the southwest for the periods of 2006–2030 and 2035–2060 predict an increase in drought severity with surface warming. Additionally, drought still increases during wetter simulations because of the effect of heat-related moisture loss (Hoerling and Eicheid 2007, p. 2). Annual average precipitation is likely to decrease in the southwest, as are the length of snow seasons and snow depth (Hicke et al. 2022, pp. 1953-1954). Most models project a widespread decrease in snow depth in the Rocky Mountains and earlier snowmelt (Hicke et al. 2022, pp. 1952-1954 and 1971). Changes in amount or type of winter precipitation may affect snowpack levels, which in turn would affect the amount of surface and subsurface moisture. Low or no snowpack levels could change the amount and reliability of subsurface moisture for the rest of the year and lead to an increase in aboveground and subsurface temperatures that are unsuitable for the salamander (Wilson et al. 2020, p. 706). Additionally, since the salamander spends most of its time underground, it is likely that low or no snowpack levels would cause changes in underground temperatures and provide less insulation for subsurface salamanders, resulting in the need for salamanders to travel deeper underground (which may result in salamanders using more stored fat).

Precipitation predictions are based on continental-scale general circulation models that do not yet account for land-use and land-cover change effects on climate or regional phenomena, and therefore, changes in precipitation are more difficult to predict. Consistent with recent observations, the outlook presented for the southwest and New Mexico predicts warmer, drier, drought-like conditions (Hoerling and Eischeid 2007, p. 2; Seager et al. 2007, p. 1181). Climate model predictions do suggest overall warming temperatures throughout North America under all modeled scenarios (Intergovernmental Panel on Climate Change [IPCC] 2021, p. 14; 2022, p. 8). Rising temperatures are expected to increase evaporation and make microclimate conditions (humidity levels at soil surface and underground) less suitable for salamanders. If warmer temperatures are not counter-balanced by increased precipitation, the species will face increased drought-like conditions. Increases in drought frequency and intensity may increase habitat conversion (Garfin et al. 2014, p. 465), which may lead to a decrease in the extent of suitable habitat for salamanders.

Environmental changes may also increase precipitation events such as flooding and runoff, which may result in less ground infiltration. Models are projecting an increase in frequency of heavy downpours, and some even show an increase in daily extreme summer precipitation (Gonzalez et al. 2018, p. 1110), although projections of summer total precipitation are uncertain. Drought has also caused earlier spring snowmelt and shifted runoff to earlier in the year. Within the past 50 years, the southwestern U.S. has seen less late-winter precipitation falling as snow, snowmelts occurring earlier, and earlier arrival of most of the year's streamflow (Pierce et al. 2008, entire; Hidalgo et al. 2009, entire; Garfin et al. 2014, p. 465; Gonzalez et al. 2018, p. 1109). Warmer winter temperatures in the Sierra Nevada are projected to increase winter runoff (Gonzalez et al. 2018, p. 1121), and similar impacts in the Jemez Mountains could mean less ground infiltration during winter and drier subsurface conditions in the summer. Changes in precipitation, snowmelt, and runoff may impact how far underground salamanders travel or when they come aboveground.

Drought likely affects *Plethodon* salamander physiology and behavior (see sections 2.3.1 Behavior through 2.3.4 Movement) and population viability. Increasing temperatures and decreasing precipitation in the Jemez Mountains have occurred as a local expression of regional changes in environmental conditions, including warming and drought. Jemez Mountains salamanders are ectothermic (meaning they cannot physiologically regulate their body temperature), and temperature and moisture often drive salamander behavior and physiology; thus, salamanders tend to choose cover objects that help them retain moisture and stabilize their internal temperature (Carey 1987, p. 9). Because the salamander is terrestrial, constrained in range, and isolated to the higher elevations of the Jemez Mountains, increased ambient temperature and reduced moisture could alter microclimate conditions such that they become insufficient for salamander movement or survival, resulting in loss of suitable cover objects or habitat at local or broader scales, potentially impacting the range via elevation or aspect. Additionally, increases in temperature and decreases in moisture/drying can greatly impact the species' demographic attributes (e.g., reproductive success and salamander survival) and behavior (e.g., foraging and breeding), primarily by influencing the timing and duration of aboveground activity (see Figure 5.1 for more information).

The effects of drought influence other stressors, including erosion (accelerating hydrologic runoffs from vegetation loss), insect damage/tree disease (impacting tree health, which makes trees more susceptible to insects and disease), and wildfire (increasing wildfire chances via drier forests and habitat; Figure 5.1).

Wildfire

Uncharacteristic drought cycles are contributing to a changing fire regime in the west (Westerling et al. 2006, pp. 941-943). Drought and rising temperatures reduce moisture in the environment. This increases wildfire risk by reducing moisture levels in dead fuels (wood and other vegetation) and stresses trees and other live vegetation, increasing their susceptibility to disease and pests. Westerling et al. (2006, p. 940) showed that "large wildfire activity (in the western U.S.) increased suddenly and markedly in the mid-1980s, with increased large-wildfire frequency, longer wildfire durations, and longer wildfire seasons." Singleton et al. (2019, pp. 10-12) also showed that the frequency, severity and size of wildfires, in Arizona and New Mexico specifically, have increased since the mid-1980s. From 1984 to 2015, area burned and area of high-severity burn increased for all ecological response unit (ERU) fire types, and the percent of high-severity fire increased in two ERUs (mixed-conifer and mixed conifer with aspen/spruce-fir; Singleton et al. 2019, pp. 2 and 26). During a period of extreme drought in Arizona (1997-2007), Ganey and Vojta (2011, entire) found tree mortality in mixed-conifer and ponderosa pine forests to be severe; the number of trees dying over a 5-year period increased by more than 200 percent in mixed-conifer forest and by 74 percent in ponderosa pine forest during this timeframe. Ganey and Vojta (2011, pp. 164-165) attributed the die-offs of trees to drought and subsequent insect (bark beetle) infestation. This increase in susceptibility of high-elevation forests to high-intensity wildfires could, if available fuels are present, increase the area of forest burned in Arizona and New Mexico by 380 percent by the year 2100 (Fleishman et al. 2013, pp. 158-159).

Prior to ESA listing of the salamander, the Jemez Mountains experienced severe wildland fires including the 2011 Las Conchas Fire, which burned over 150,000 acres (60,703 ha;) and the 2013 Thompson Ridge Fire, which burned approximately 24,000 acres (9,712 ha). The 2013 salamander listing rule identified wildfires, and specifically severe wildfires, as one of the principal threats to the species (USFWS 2013a, entire), and it continues to be a principal threat. Since the 2013 listing, approximately

70,000 acres (28,328 ha) have burned within the range of the Jemez Mountains salamander, with the recent 2022 Cerro Pelado fire accounting for over half of this amount (Table 5.1). Wildland fire data from the U.S. Forest Service and U.S. National Park Service (2000-2022) indicate that almost half of the range of the Jemez Mountains salamander has been impacted by one or more wildland fires since 2014 (Figure 5.2). Across the salamander's range, approximately 309,724 acres (125,340 ha) of habitat have been unimpacted by wildfire or other managed treatments in the last 20 years. This habitat may be the most vulnerable to wildfires in the future, but risk of high-severity wildfires in this area likely varies across the landscape based on forest type and tree density. Modeling efforts can help us estimate the amount of aboveground habitat impacted by wildfires; however, impacts to below-ground habitat or direct impacts to salamanders from high-intensity or -severity wildfires are unknown to date.

Table 5.1. U.S. Forest Service and U.S. National Park Service wildland fire information for the Jemez Mountains in Los Alamos, Rio Arriba, Sandoval, and Santa Fe counties, New Mexico from 2014 (after the Jemez Mountains salamander was federally listed) to 2022. Note: Wildfire suppression response is influenced by a variety of factors and varies by fire. Data were obtained from the U.S. Forest Services' Southwest Region Fire History Occurrences dataset. Zero acreage fires totaled less than 0.5 ac. Prescribed fires are not included.

Year	Fire Cause	Name	Total Acres
2014	Natural Ignition	Diego	3,615
2014	Natural Ignition	Bear Springs	26
2014	Natural Ignition	Pino	4,284
2016	Natural Ignition	Cuerno	699
2016	Natural Ignition	Virgin Mesa (Canyon)	96
2016	Natural Ignition	138	323
2016	Natural Ignition	Banco Bonito Cajete 3 & 5 North Big Hat	217
2016	Natural Ignition & Broadcast Burning	Virgin Mesa	1,276
2017	Natural Ignition	Deer Creek	1,022
2017	Natural Ignition	Borrego	11
2017	Human Ignition	Cajete	1,412
2017	Natural Ignition	Peggy	887
2017	Natural Ignition	Peggy WFU	887
2018	Natural Ignition	Chicoma	42
2018	Natural Ignition	Alamo	15
2018	Natural Ignition	Venado	4,063
2018	Natural Ignition	Bales (2)	14
2018	Natural Ignition	San Antonio (large)	412
2018	Natural Ignition	San Antonio (small)	5
2018	Natural Ignition	Hidden Valley	585
2018	Natural Ignition	Cabin	0
2018	Natural Ignition	Venado	2,945
2019	Natural Ignition	Conejos	777
2019	Natural Ignition	Naranjo	1,010
2022	Human Ignition	Cerro Pelado	45,605

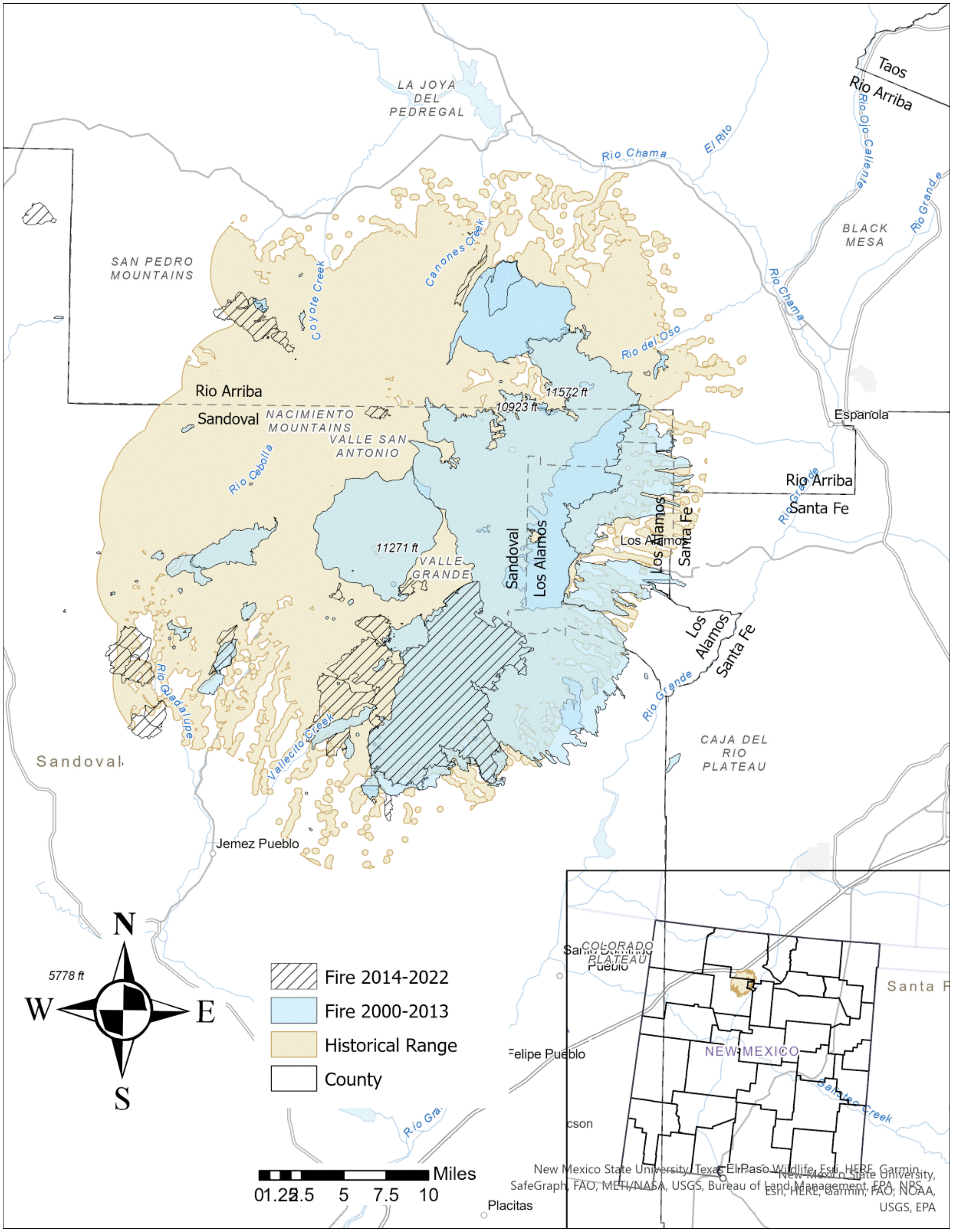

Figure 5.2. Historical range of the federally endangered Jemez Mountains salamander showing wildland fire information (from U.S. Forest Service and U.S National Park Service) from two timeframes, including 2000 to 2013 (the year the Jemez Mountains salamander was federally listed), and 2014 to 2022, for the Jemez Mountains in Los Alamos, Rio Arriba, Sandoval, and Santa Fe counties, New Mexico.

Low-severity fires were historically dominant across the Jemez Mountains salamander's range, with historical fire return intervals varying between high frequency (mean fire return interval [MFI] of 10 years) and moderate frequency (MFI of 42 years) (Margolis and Malevich 2016; entire). Given the historical landscape, we assume that Jemez Mountains salamanders are more adapted to low- to moderate-severity fires and smaller scale fires with localized high-severity impacts. In southwestern forests such as the Jemez Mountains, fire scar data indicate that fire regimes typical of Ponderosa pine forests (high-frequency, low-intensity fires) almost ceased to occur following substantial land-use changes associated with railroads, logging, fire suppression, and livestock grazing; activities that altered natural fuel loads (Covington and Moore 1994, pp. 40-45; NMDGF 2016, p. 43). Because low-severity fires were more frequent prior to the arrival of railroads, it is likely that impacts to Jemez Mountains salamanders and their suitable habitat were lower. These fires likely left more standing trees and herbaceous vegetation (benefiting salamander microclimate conditions by providing more shade and moisture), and coarse woody debris. Wildfires and, in particular, high-severity wildfires, have become more frequent within the western U.S., including in the Jemez Mountains. In western U.S. forests from 1985 to 2017, there was an eightfold increase in forest area burned at high severity, as compared with fires prior to 1985 (Parks and Abatzoglou 2020, entire). More wildfires are projected in the future based on numerous fire models (Krawchuk et al. 2009, entire; Moritz et al. 2012, entire; Gonzalez et al. 2018, entire), meaning it is likely that the number of western forests burning at high severity will increase. Furthermore, as environmental changes create new fuelscapes, existing management strategies may not be able to prevent the reorganization of forest ecosystems (Loehman et al. 2018, pp.12-18 and p. 20). Drought (discussed above) and insect damage/tree disease (discussed below in section 5.3 Environmental and Human Development Stressors Not Included in Viability Analysis) will likely amplify the effects of wildfires throughout the salamander's range, which may reduce the quantities of key habitat elements, including downed wood and bark for salamanders.

Since Jemez Mountains salamanders are lungless and spend most of their lives under cover objects or underground in highly localized areas (home ranges) (see chapter 2 SPECIES ECOLOGY AND NEEDS, above), microclimate variables, including temperature and moisture, are very important to their survival. Changes in microclimate can impact salamanders in many ways, including desiccation and hydration, metabolism, oxygen consumption, and other physiological functions. Cummer and Painter (2007, pp. 29-31) found that temperatures under potential salamander cover objects were significantly higher in high-severity and moderate-severity burn areas than in low-severity and unburned areas. High-severity wildfires may lead Jemez Mountains salamanders to alter their behavior, such as clustering together under sparse woody debris (Cummer and Painter 2007, p. 33) or spending more time below ground and less time feeding on the surface.

There is the potential for wildfire to be linked to other stressors, including erosion (wildfires have resulted in loss of vegetation, which can lead to accelerated hydrologic runoffs and accelerated erosion), drought (which can lead to more intense wildfires), and insect damage/tree disease (wildfires can impact tree health, which makes trees more susceptible to insects and disease; Figure 5.1).

5.2 Human Development

Human population growth and associated anthropogenic development have historically impacted Jemez Mountains salamanders through habitat alteration and destruction. This source causes numerous stressors that negatively impact the resources needed by Jemez Mountains salamanders, thereby impacting the species' demographic attributes (e.g., reproductive success, adult and subadult survival) and resulting viability. Below we discuss stressors linked to the overarching source of human development, including disease, fire and forest management (including dust abatement compounds, herbicide application, planting treatments, and timber or fuelwood harvest), and wildfire. Stressors associated with human development that we did not carry forward into our analysis of future condition include erosion, grazing, illegal collection, infrastructure development/maintenance, recreation, and research activities. See section 5.3 Environmental and Human Development Stressors Not Included in Future Viability Analysis for more information on these stressors. Figure 5.3 below provides an overview of how the source of human development relates to these stressors and resources/habitat needed to maintain and improve Jemez Mountains salamander viability.

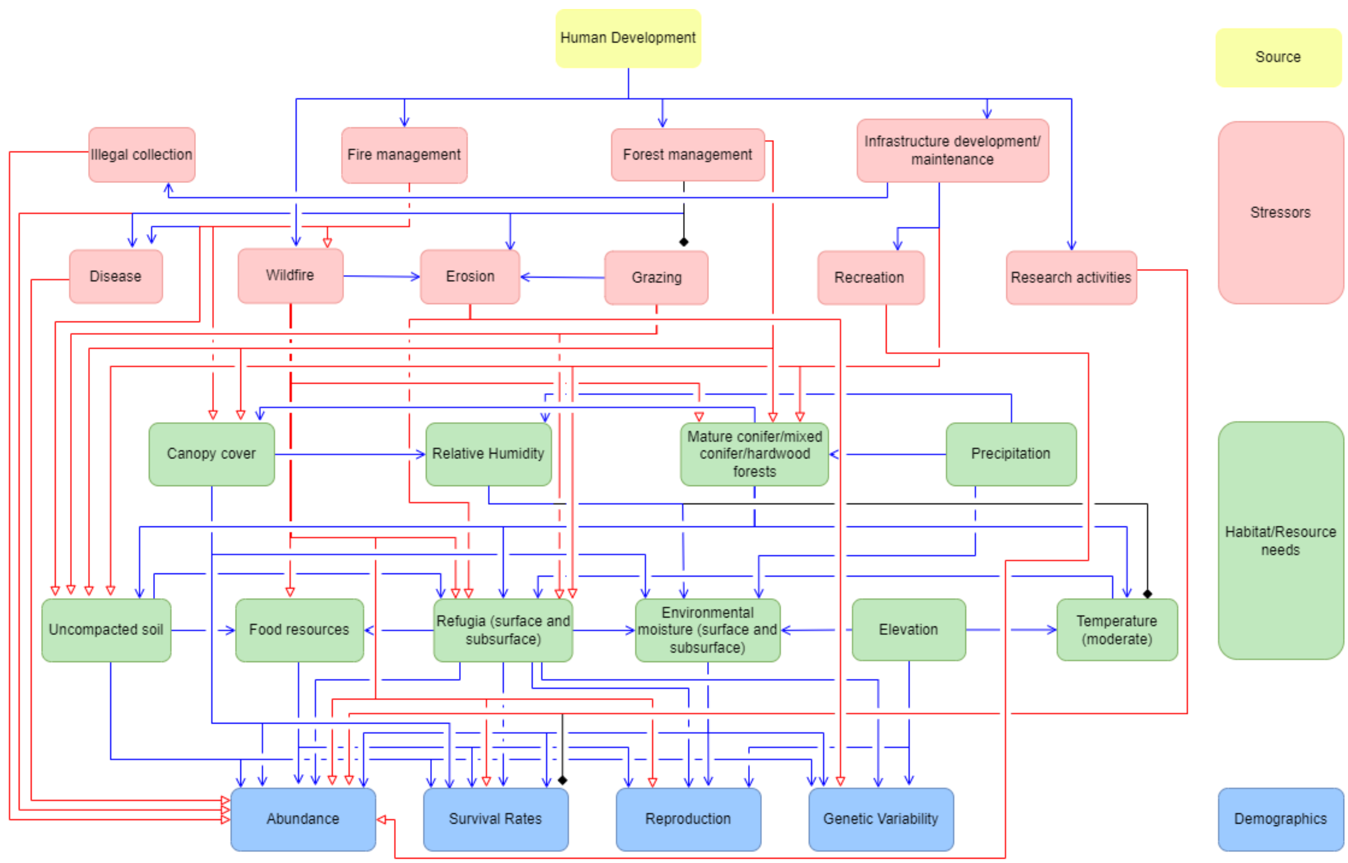

Figure 5.3. Conceptual model developed by the SSA Core Team illustrating the relationship between human development and resulting stressors to both habitat and resources essential to Jemez Mountains salamander viability. These relationships are discussed throughout this chapter. Note that arrow colors correspond to positive (blue, line arrow) or negative (red, hollow arrow) relationships; a black arrow, closed diamond, indicates that the relationship may be either positive or negative.

Disease

Infectious diseases, including those caused by chytrid fungus (*Batrachochytrium dendrobatidis*) and ranaviruses (family Iridoviridae), have been linked to amphibian declines over the last few decades (Daszak et al. 1999, entire; Gray et al. 2009, entire). Another fungal pathogen (*Batrachochytrium salamandrivorans* [Bsal]) has more recently been discovered in Europe as an emerging infectious disease of salamanders (Martel et al. 2013, entire), raising significant concerns about potential impacts to North American amphibians. All three pathogens have the potential to be transmitted to and cause disease in Jemez Mountains salamanders.

Batrachochytrium dendrobatidis (Bd) is a pathogenic fungus that infects amphibians. Bd is often considered an aquatic pathogen because it has motile zoospores that can disperse through the water. However, Bd is also known to occur in strictly terrestrial species like the Jemez Mountains salamander. Bd causes the disease chytridiomycosis. Bd fungus attacks the skin of adult amphibians, and the symptoms of chytridiomycosis can include sloughing of skin, lethargy, morbidity, and death. Bd achieves optimal growth in water that is between 17 – 25 °C (62 – 77 °F), and in the wild most disease outbreaks occur seasonally, at higher elevations, and during wet, cooler months (Partners in Amphibian and Reptile Conservation 2022, p. 2). Chytridiomycosis has been linked with worldwide amphibian declines, die-offs, and extinctions, possibly in association with changes in environmental conditions (Pounds et al. 2006, p. 161).

In 2003, Bd was found in a wild-caught Jemez Mountains salamander on the east side of the species' range, and then again in 2010, 2012, and 2017 (three different salamanders) on the west side of the species' range (Cummer et al. 2005, p. 248; Pisces Molecular 2010, p. 3; L. Pierce, pers. comm.). Sampling for Bd from Jemez Mountains salamanders has been limited. Cummer (2006, p. 2) reported that noninvasive skin swabs from 66 Jemez Mountains salamanders, 14 boreal chorus frogs (*Pseudacris maculata*), and 24 tiger salamanders (*Ambystoma tigrinum*) from the Jemez Mountains were all negative for Bd. Approximately an additional 30 Jemez Mountains salamanders were tested through 2010 with no positive Bd results. In subsequent sampling of 140 salamanders swabbed from 2019-2024, 46 percent were positive for Bd. However, no individuals showed obvious signs of disease (N. Karraker, pers. comm.). Detection of Bd in the Jemez Mountains salamander indicates the species has been exposed to the pathogen and could acquire infection. It is unknown how susceptible the salamander is to chytridiomycosis, or how the Bd-positive salamanders encountered the fungus. Although Bd can be highly infectious and can lead to disease and death, the pathogenicity of Bd in amphibians varies greatly among and within amphibian species. Further research is needed.

Ranavirus is a double stranded deoxyribonucleic acid (DNA) virus that can cause severe infections in a number of cold-blooded taxa, including amphibians, reptiles, and fish. In amphibians, this virus can impact juvenile and adult age classes. Disease and death may happen within 3 days but can take weeks. Death results from severe cellular/organ necrosis. Clinical signs of ranavirus in aquatic salamanders can include lethargy, buoyancy problems, and erratic swimming. Gross lesions may include swelling (neck, appendages, body), hemorrhages (especially on ventrum and legs [amphibians]), tan friable organs, ulceration, and oral necrotic tan plaques (in turtles). (ACVP 2015, entire). Ranavirus has been detected in New Mexico from tiger salamanders used as bait for fishing (Picco and Collins 2008, p. 1586). It was also recently detected from two rivers in the southern part of New Mexico during a pathogen study (Johnson and Fritzler 2019, pp. 11-13). Ranavirus was detected in 5 percent of 140 Jemez Mountains salamander individuals (swabbed 2019-2024), though none showed obvious signs of disease (N. Karraker, pers. comm.). The impacts of this disease on Jemez Mountains salamanders are currently unknown but could potentially lead to the death of infected individuals and declines in populations.

Bsal was first reported from dead salamanders found in the Netherlands (Spitzen-van der Sluijs et al. 2013, entire). Since its discovery, it has been found in or spread to other European countries. Currently, there are no known records of Bsal from the U.S. (thus no New Mexico records). The impacts of this disease on Jemez Mountains salamanders are currently unknown, but it would likely lead to the death of infected individuals and declines in populations.

There is the potential for the previously mentioned (and potentially unknown or new) diseases to be linked to other human development stressors including forest and fire management, infrastructure development/maintenance, recreation, and research activities (for all, if equipment or gear is contaminated and not disinfected, diseases can be transported to areas occupied by salamanders), and grazing (if cattle use aquatic areas contaminated by diseases, then transport the pathogen to upland areas occupied by salamanders; Figure 5.3).

Fire management

Past forest fire management practices in the Jemez Mountains, such as fire suppression and exclusion, fire and fuel management, and post fire rehabilitation have created densely packed forests with an overabundance of woody vegetation. To address the effects of past forest fire management practices, natural resource agencies including the U.S. Forest Service and U.S. National Park Service have started using integrated forest fire management. This type of management utilizes a systematic approach that encompasses both the traditional efforts of fire prevention and fire suppression, the application of prescribed fire as a tool, and the engagement of communities with properties adjacent to public lands. The purpose of forest fire management is to protect life, property, and other identified resources needing protection. Although fire suppression is still an active management activity, fire is used as a tool to accomplish resource management objectives of restoring environmental health and ecological integrity. Communication and coordination occur within communities and near the area under consideration for forest fire management. This approach is used to restore and maintain fire-dependent communities that are more in line with historical conditions.

Using fire in a safe, controlled manner is key to forest restoration. This includes using fire for fuels management with planned prescribed fire and, in some situations, letting wildfires burn to achieve management objectives, termed managed fire. Over a 50-year timeframe, a study found that repeated fire was critical to reducing tree density by about half in several forests. Fire was also important in maintaining the soil nutrients necessary for tree growth (Pellegrini et al. 2021, entire). Overcrowded forest conditions prevent trees and other plants from obtaining the nutrients, light, or water needed to bounce back and remain healthy following a stressful event. Historically, fires in the Jemez Mountains kept fuel loads low, but over time, with management favoring fire exclusion, forest densities in the Jemez Mountains increased, which led to the development of heavy accumulations of dead and downed fuel (Allen 2001, p. 6). The disruption of the natural cycle of fire and subsequent accumulation of continuous fuels within the coniferous forests on south- and north-facing slopes has increased the chances of a severe wildfire affecting large areas of salamander habitat within the Jemez Mountains (USFS 2009a, entire; 2009b, p. 1). Fuels management activities can involve using mechanical (heavy or manual) equipment to chip/masticate/cut vegetation or creating piles that can be burned at a later date. Mechanical treatment of hazardous fuels, such as manual or machine thinning (chipping and mastication), may cause localized disturbances to the forest structure or alter ecological interactions at the soil surface that can impact the salamander and its habitat (USFWS 2013a, p. 55614). Piles created through fuels management are built in conical shaped piles (stacking small woody debris vertically) and are burned during the winter within one to two years after being built so that the piles do not decay enough for salamanders to use. Forest and fuels management are likely to reduce but will not eliminate wildfire risk. The warming climate further stresses vegetation and can foster tinderbox conditions on the landscape, especially under widespread persistent drought. All these factors can lead to changes in suitable Jemez Mountains salamander habitat conditions.

Forest fire management activities that may occur in Jemez Mountains salamander suitable or occupied habitat include trained individuals conducting prescribed burns and creating burn lines, and wildfire suppression activities, including the use of fire retardant, helicopter water drops, back burns, and heavy equipment and hand crews to create control lines. Such activities likely impact salamanders and their habitat through the reduction of standing timber (reduction of canopy cover which may increase surface temperatures and reduce soil moisture) and woody cover objects; however, the reduction of standing timber will likely reduce the frequency of high-severity wildfires and should, in the long-term, create woody cover objects. The overall impact, long-term and range-wide of these forest fire management activities on salamanders is currently unknown and may need to be examined in further detail in the future.

There is the potential for fire management to be linked to other human development stressors including disease (diseases can be transported to areas occupied by salamanders if contaminated equipment or gear used for fire management is not disinfected prior to use), forest management, infrastructure development/maintenance, recreation, research activities, and grazing (if cattle use aquatic areas contaminated by diseases and then move to upland sites occupied by salamanders, they may transport and introduce diseases to these areas; Figure 5.3).

Forest management

Forest management includes activities such as use of dust abatement compounds, herbicide application, planting treatments, and timber thinning/fuelwood harvest. Dust abatement compounds are used to reduce the ability of dirt and other surface particles to be lifted and suspended by vehicle tires or wind. Santa Fe National Forest's recent Land Management Plan includes guidelines for air which states that "*Dust abatement should occur during construction and road projects where dust is a potential effect*" and that "*when possible, consider using non-potable water for dust abatement strategies*" (USFS 2022c, p. 98). Dust abatement compounds include a wide variety of commercially available suppressants that can typically be divided into seven categories: water, water-absorbing products, petroleum-based products, organic nonpetroleum-based products, electrochemical products, polymer products, and clay additive products (Bolander and Yamada 1999, entire). The impacts of these products on salamanders are currently unknown. Although water is the recommended dust abating compound, the prevalence of use of the various compounds and their potential impact on salamanders is unknown.

Herbicide application is used in forest management to help control non-native vegetation growth. This activity involves transportation of chemical herbicide on vehicles or in back-pack sprayers. The herbicide is applied onto vegetation during the growing season (typically May – September). Herbicide application typically targets non-native vegetation species and should not be used on native vegetation. However, some herbicides may reside in soils for long periods of time, which may inhibit the growth of native vegetation (USFS 2022a, p. 162). The impacts of herbicides on Jemez Mountains salamander are currently unknown, and studies have shown mixed results on impacts on terrestrial amphibians. Studies including Cole et al. (1997, entire), McComb et al. (2008, entire), Jones et al. (2000, entire), and Bernal et al. (2009, entire) found little impact on species from herbicide application. However, Gertzog et al. (2011, entire) did note that eastern red-backed salamanders (*Plethodon cinereus*) seemed able to detect and avoid certain types of herbicides.

Following disturbances such as stand-replacing fire, regeneration of mature forests is needed to replace impacted salamander habitat. Forest succession, a long process, is influenced by a number of variables including competing vegetation, variability in cone production, and reduced seed viability, which may be linked to climate and many other factors (Stevens-Rumann and Morgan 2019, p. 11). When it has been determined that intervention is needed to ensure regeneration of trees post-disturbance, forest management practices such as tree planting may be implemented. Planting treatments involve the use of either hand or mechanical tools to plant trees. Planting treatments occurring in suitable or occupied salamander habitat when aboveground activity is likely could impact Jemez Mountains salamanders, since the activities associated with treatments involve soil-disturbing activities. There are records of soil-disturbing activities during which a Jemez Mountains salamander has been observed (Latella 2017, entire; K. Driscoll, pers. comm.). Although activities associated with planting treatments can result in habitat damage or loss and individual salamander injury or death, their impacts are currently unknown.

Timber thinning and fuelwood harvest activities on public lands involve the removal of standing trees by contractors or the collection of downed wood for use by the public. Forest thinning operations generate biomass that must be treated on site. This biomass includes slash and smaller-diameter logs that are piled according to specifications and then left to dry for a year or two. Burning of slash piles (accumulated materials from forest management activities) is commonly used to dispose of any non-harvested woody material. Pile burning is an efficient and effective technique to reduce both future fire risk and extreme fire behavior (Mott et al. 2021). Sacramento Mountain salamanders (*Aneides hardii*), another lungless salamander endemic to New Mexico, have been detected under unburned, constructed slash piles associated with forest management treatments within the Lincoln National Forest. Salamanders were located within piles (log contact surfaces) and at the interface between logs and the soil surface (R. Loehman and N. Karraker, pers. comm.). Slash pile management does occur within the Jemez Mountains salamander's range, but no salamanders have been found during pile burning (Trader 2021; entire). Piles are typically burned during the colder months or when snow is on the ground, so this reduces the potential for salamanders to be active above ground at the time of ignition. However, little is known about the potential for impacts to salamanders that may be utilizing the subterranean habitat below the pile at the time it is burned. For forest thinning operations implemented with the use of heavy machinery to cut, remove, stack, and masticate logs, these activities can compact the soil, smash fossorial tunnels, and change travel routes for salamanders. Thinning practices can reduce canopy cover and increase temperatures on the forest floor where timber was removed. Although downed logs can provide cover objects on the forest floor, they can also contribute to fuel loads which can influence wildfire behavior (e.g., rate of spread and severity). While fuelwood collection can reduce forest fuel loading, it can lead to soil compaction when vehicles are driven off main roads and can also result in the removal of large-diameter logs that could provide current or future cover for salamanders.

There is the potential for forest management activities including application of dust abatement compounds, herbicide application, planting treatments, and timber/fuelwood harvest to be linked to other human development stressors including disease (transporting diseases on equipment or vehicles), fire management (timber/fuelwood harvest may increase downed wood which can contribute to fuel loads), and infrastructure development/maintenance (dust abating compounds used on roads; Figure 5.3).

Wildfire

Impacts of wildfire are discussed in section 5.1 Environmental Changes above. As described above, wildfire activity (frequency, duration, season) has increased from historical levels or is projected to increase in the western U.S. (Westerling et al. 2006, p. 940; Krawchuk et al. 2009, entire; Moritz et al. 2012, entire; Garfin et al. 2014, entire; Parks and Abatzoglou 2020, entire).

Human population growth and associated anthropogenic development will likely also contribute to increased wildfire activity. As the number of people increases, human activities that may cause wildfires (including campfires, cigarettes, automobile mufflers) within natural areas including within the Jemez Mountains salamander range are likely to increase. In response to the increasing human population and associated use and occupancy of natural areas, state and federal agencies may increase their prescribed fire and thinning activities to reduce the risk or impact of wildfire on the landscape within the Jemez Mountains salamander's range. These activities would increase impacts on Jemez Mountains salamanders and their aboveground and below-ground habitat, and may reduce the quantities of key habitat elements, including downed wood and bark.

There is the potential for wildfire activities to be linked to other human development stressors including erosion (wildfires have resulted in loss of vegetation which can lead to accelerated hydrologic runoffs and accelerated erosion; Figure 5.3).

5.3 Environmental Changes and Human Development Stressors Not Included in Future Viability Analysis

Erosion

The Jemez Mountains have undergone a variety of changes due to increased human activity across the landscape. This human activity includes fire suppression, forest management, logging, grazing, mining, and recreation (Allen 1989, p. 3). All these activities may contribute to erosion. The history of fire suppression and fire exclusion in the Jemez Mountains has led to increases in high-intensity wildfires in and around the area (see sections 5.1 Environmental Changes and 5.2 Human Development for additional information on wildfire, above). These high-intensity wildfires have resulted in loss of trees and other surface vegetation on mountain slopes, which in turn has led to accelerated hydrologic runoffs and accelerated erosion (Allen 2007, entire). Wildfires followed by substantial rainfall can result in large, destructive debris flows. Debris flows can have catastrophic impacts on the surrounding landscape and habitat. In the Jemez Mountains, the probability of debris flows in response to a 100-year-recurrence interval and 30-minute duration rainfall event averaged 37 percent, with 13.4 percent of all subbasins (671 subbasins) having debris-flow probabilities greater than 80 percent (Tillery and Haas 2016, p. 23). Additionally, fire can cause hydrophobic soil conditions to form. The proximity and size of hydrophobic soil patches and depth of hydrophobicity increase with fire and can be long lasting (Huffman et al. 2001, pp. 2881-2890; Woods et al. 2007, pp. 472-477), suggesting the potential for long-term effects of wildfire induced run-off/erosion and declined quality of salamander habitat from reduced below ground moisture. Along with wildfires, historical livestock grazing has contributed to changes in the Jemez Mountains ecosystem (see Grazing, below) which has contributed to increased soil erosion (USFWS 2013a, p. 55619). Additionally, recreation activities including road and trail creation can also lead to erosion (see Recreation, below). Currently, erosion occurs throughout the Jemez Mountains salamander's range and impacts important habitat components, including relative humidity and refugia through removal of vegetation and cover objects which increase bare ground connectivity (Allen 2007, entire). By impacting the important habitat components mentioned above, erosion could lead to a reduction in optimal aboveground refugia needed for reproduction and potentially contribute to reduced Jemez Mountains salamander genetic variability. Given the information we currently have, erosion may need to be examined in further detail in the future since it is considered a minimal-impact stressor and may be linked to other stressors that may have important impacts on Jemez Mountains salamanders.

Grazing

Grazing is a historical and ongoing activity throughout the range of the Jemez Mountains salamander. Livestock grazing removes understory grasses which alters the composition and structure of the vegetative community. Excessive loss of vegetation leaves soils exposed and impacts important salamander habitat components including relative humidity and refugia (see Erosion, above). Additionally, as livestock use or move through areas, they can damage or destroy delicate cover objects and compact soils. Currently, livestock grazing occurs infrequently within Jemez Mountains salamander habitat, because livestock tend to concentrate outside of forested areas where grass and water are more abundant (USFWS 2013a, p. 55619) and slopes are gentler (Roath and Krueger 1982, entire). However, small-scale habitat modification, such as livestock trail establishment or trampling in occupied salamander habitat was included as a possibility (USFWS 2013a, p. 55619); and recent observations support this conclusion, as livestock have been frequently observed moving through important Jemez Mountains salamander habitats and degrading and disturbing salamander cover objects (N. Karraker, pers. comm.). Given the information we currently have, grazing may need to be examined in further detail in the future since it is considered a minimal-impact stressor and may be linked to other stressors that may have important impacts on Jemez Mountains salamanders.

Illegal Collection

Historically, before its federal listing, large numbers of Jemez Mountains salamanders were collected from different locations throughout its range. These collections included the "type locality" in the southern portion of the salamander range described as having an "abundant salamander population" (Reagan 1967, p. 8) where 165 salamanders were collected in 1965 and 1967, and at least 67 more salamanders collected in 1970 (Williams 1972, p. 11). Later, Painter (1999, p. 1) reported that nearly 1,000 salamanders were collected from the "type locality." Since the 1990s, subsequent surveys at this location have not detected salamanders (USFWS 2013a, p. 55620). Those collections, though legal at the time, highlight the impacts that illegal collection could have on the species. Recreational use of forest areas could contribute to illegal collection (see Recreation, below). Currently, collection of the species is regulated through permits issued by USFWS and the New Mexico Department of Game and Fish (USFWS 2013a, p. 55620), and we have no observations suggesting ongoing illegal collection for trade. Given the restrictions on collection and the rarity and cryptic nature of the species, we consider illegal collection to be a minimal-impact stressor on the salamander currently. An increase in interest from herpetological enthusiasts in finding and observing the salamander to complete "life lists", and communicating sensitive information using social media, could have a substantial negative impact on the species (e.g., habitat destruction, disease transmission, etc.) and may need to be examined in further detail in the future as additional information becomes available.

Infrastructure development/maintenance

Infrastructure includes roads, trails, well drilling, range improvements (well, water line, fencing, corrals), utility corridors (gas and electric), developed recreation sites, homes and associated outbuildings, etc. These types of infrastructure can be found throughout the Jemez Mountains on Forest Service, National Park Service, Department of Energy, state, private, and local government lands. Development, maintenance, and repair of infrastructure (activities) are expected to continue into the future. Activities have occurred and are likely to continue to occur within suitable Jemez Mountains salamander habitat. However, the majority of the activities (roads and utility corridors) occur in habitat currently considered unsuitable for the species. Jemez Mountains salamanders, however, have been encountered during activities associated with infrastructure maintenance and development. For example, 12 individuals were captured and translocated during the construction of New Mexico highway 126 (Watson 2007, entire) and 1 salamander was encountered during pipeline maintenance activities (Latella 2017, entire). Pipeline activities prior to 2017 and until 2020 did not encounter another Jemez Mountains salamander (Latella 2020, entire). Some of these activities (with regards to roads and trails) can lead to increases in recreation use (see Recreation, below) within Jemez Mountains salamander habitat. All these activities can impact Jemez Mountains salamander; however, because most occur already in existing disturbed habitat, we consider this to be a minimal-impact stressor.

Insect damage and tree disease

Insects and diseases are important components of forest ecosystems and greatly influence forest structure and species composition over time. In the southwestern U.S., insects including bark beetles and defoliators, and diseases including mistletoe, stem decay/rust, canker fungi, and foliar disease have impacted national forest lands in recent years (USFS 2022b, entire). Since Jemez Mountains salamanders occur in forested habitat, insects and disease may impact important salamander forest habitat components. Alteration of forest composition and structure contribute to increased risk of forest die-offs from disease and insect infestation throughout the range of the salamander (Allen 2001, p. 6; USFS 2002, pp. 11-13; 2009a, pp. 8–9; 2009b, p. 1; 2010, entire). Forest die-offs from disease or insect infestation, environmental changes, and management actions associated with controlling and containing insect and disease outbreaks would affect the salamander by reducing canopy closure, warming or drying the soil and cover objects, and increasing dry fuel loads that influence the scale and severity of wildfires (e.g., see sections 5.1 Environmental Changes and 5.2 Human Development for additional information on wildfire, above). Given the information we currently have, insect damage and tree disease, and management actions associated with controlling and containing insect and disease outbreaks, may need to be examined in further detail in the future since it is considered a minimal-impact stressor and may be linked to other stressors that may have important impacts on Jemez Mountains salamanders.

Recreation

Federal and state lands in the Jemez Mountains are heavily used for recreational activities, including camping, hiking, mountain biking, hunting, fishing, skiing, and off-road highway vehicle (OHV) use. These activities occur in Jemez Mountains salamander suitable and occupied habitat and have the potential to differentially impact the salamander and its habitat. As human populations in New Mexico continue to expand, demand for recreational opportunities in the Jemez Mountains will likely increase. Individually, recreational activities that are small in scale, such as hunting, hiking, fishing, or dispersed camping are considered low-impact stressors; however, the additive nature of recreational activities that include or contribute to activities that are larger in scale, such as OHV use and ski area expansions, may be considered a greater stressor to the species. In addition to these activities, recreation use may spread diseases or pathogens that may impact the salamander. Trails throughout the area include both agency-managed trails along with those developed by visitors establishing their own network of user-created trails. Erosion caused by heavy trail use by motorcycles or OHVs can form trenches, which may prevent salamander movement, fragment local populations, and trap salamanders that fall into the trenches. Therefore, OHVs and motorcycles could severely impact the salamander's habitat (USFWS 2013a, p. 55618). Additionally, mountain biking, OHV use, hiking, and camping may result in direct mortality and the loss of cover objects required for breeding, feeding and shelter during the monsoon season, through the crushing of individuals or cover objects or soil compaction during operation of bikes and OHVs, moving rocks to build campfire rings, and burning of cover objects in campfires. Many roads in the Jemez Mountains are accessible to the public for recreational use and may contribute to illegal OHV activity and increased access to areas occupied by the Jemez Mountains salamander. When coupled with increasing use of public lands, this may contribute to targeted and naive incidences of illegal collection (see Illegal Collection, above) or increases in the spread of diseases or pathogens (see Disease above). Given the information we currently have, recreation may impact the Jemez Mountains salamander but may need to be examined in further detail in the future since we currently consider this to be a minimal-impact stressor due to the rarity of the species and lack of reported instances of recreation activities causing direct mortality.

Research activities

Research activities include any and all types of research including those not associated with gathering information specific to the Jemez Mountains salamander and its habitat. Research activities may occur in unsuitable, suitable, or occupied salamander habitat. Activities occurring in suitable or occupied habitat have the potential to impact salamanders or important salamander habitat features (like cover objects), especially if conducted when salamanders occur aboveground. Research activities occurring on U.S. Forest Service or U.S. National Park Service lands are regulated through permits issued by those agencies. If it is determined that research activities may impact the species or its habitat, coordination or consultation with the USFWS will occur, and additional permitting requirements may be necessary. Due to the rarity and cryptic nature of the species, we anticipate that individuals conducting most research activities may not encounter Jemez Mountains salamanders. Based on the limited information and because of the unknown nature and types of research activities likely in the future, we consider this a minimal-impact stressor.

6 FUTURE SCENARIOS AND CONDITIONS

Previous chapters include the following information: Jemez Mountains salamander ecology (2), past and current distribution and abundance (including current habitat use; 3), the current conditions of 34 subunits (4), and stressors on viability (5). In this chapter, the viability of Jemez Mountains salamander is assessed by applying future forecasts to the species' resiliency, redundancy, and representation.

As described in the previous chapter, Jemez Mountains salamanders face varying levels of risk from stressors, including those related to human development (disease, fire and forest management, and wildfire) and those resulting from environmental changes (drought and wildfire). However, Jemez Mountains salamanders are currently state and federally listed, which offers varying levels of protection for the species. Additionally, the majority of their habitat occurs on federally owned lands, which offer higher levels of protection (e.g., under section 7 of the ESA).

Given that future stressors and levels of conservation efforts could vary from those currently in effect, we forecast future resiliency, redundancy, and representation for Jemez Mountains salamanders under three different but plausible future scenarios in the sections below:

- Scenario 1: Continuation of Current Stressor Trends and Current Conservation Actions
- Scenario 2: Moderate Stressor Increase (SSP2-4.5) and Increase in Conservation Actions
- Scenario 3: Greater Stressor Increase (SSP5-8.5) and Increase in Conservation Actions

6.1 Future Scenario Assumptions

Based on the best available information, we have made assumptions, summarized below, regarding the likelihood of occurrence and degree of threat for stressors that apply to the three potential future scenarios.

Environmental changes and human development stressors have the potential to impact the species in the future. The IPCC has provided a variety of projected future scenarios through the year 2100 (IPCC 2021, pp. 13-14). Human behaviors in the short term will determine which model is most likely to occur. In the interim, we have provided an array of scenarios to encompass a range of IPCC models. For this SSA, we consider model impacts from Shared Socio-economic Pathway (SSP)1-2.6 in Scenario 1 because of currently occurring, and potentially increasing, global adaptation to meet the 2015 Paris Agreement's 2030 and 2050 goals. Scenarios 2 and 3 include SSP2-4.5 and SSP5-8.5 respectively, should global adaptation measures decrease or cease and not meet the 2015 Paris Agreement's 2030 and 2050 goals.

6.2 Conservation Actions, Future Resiliency Factors, and Assumptions

The Jemez Mountains salamander is federally listed as endangered and is also state listed as endangered by the New Mexico Department of Game and Fish. The majority of the Jemez Mountains salamander's habitat is located on federally managed lands (see chapter 3 DISTRIBUTION, above), with some habitat located on tribal and private lands. Given these statuses and strong existing partnerships, there is certainty in the continuation of current conservation actions/measures for the salamander. Therefore, none of the future scenarios assume there will be a discontinuation of the current conservation measures.

Because the majority of the Jemez Mountains salamander's range occurs within lands managed by the Santa Fe National Forest, we used their Forest Plan Environmental Impact Statement (EIS) preferred alternative to guide consideration of potential future conditions for the species (USFS 2022c, entire). The Santa Fe National Forest Plan EIS addresses four alternatives (USFS 2022c, entire). Alternative 2, the preferred alternative, is anticipated to result in an overall increase in ecological function for wildlife (USFS 2022a, p. 59). Therefore, this SSA assumes successful implementation of Alternative 2 when assessing future conditions. The EIS assesses the availability of suitable timber and forest products for harvest. We assume that land suitable for timber production possesses necessary attributes needed for Jemez Mountains salamander aboveground activities, including breeding, feeding, and sheltering. The EIS uses a stepwise process to determine suitability, eliminating land that may not be suitable due to existing legal and technical factors, removing lands based on incompatibility with the desired forest conditions, and estimating the total amount of land suitable for timber production (USFS 2022d, pg. 249-258). In Alternative 2, there is an estimated increase of approximately 9 percent in the amount of land suited for timber production (ponderosa pine, mixed conifer, and spruce-fir forest: USFS 2022d, pg.255) and therefore assumed suitable as salamander aboveground habitat.

Across all federally managed lands, conservation actions/measures are assumed to fall into one of two categories. The first category, which is applied to Scenario 1, is continuation of current conservation actions/measures. Current actions/measures include monitoring or surveying of areas (locations or detections) known to be currently occupied, and presence or absence surveys of historical and new locations within the species' range. Current rates of monitoring at locations where research is driving monitoring intensity will decrease as the research concludes, and we assume that rates of surveying will continue as outlined in section 6.1 Future Scenario Assumptions, above. In addition to monitoring and survey efforts, the U.S. Forest Service and U.S. National Park Service conduct natural resource management, including but not limited to fuels reduction via prescribed burning or mechanical thinning, vegetation maintenance/removal, planting, trails and road maintenance, and range and watershed management. For natural resource management, we assume that current types and levels of prescribed fire and habitat modifications (through forest management practices) will continue over the next 15 years. The second category, which is applied to Scenarios 2 and 3, is an increase of conservation actions/measures. These could include monitoring of newly identified occupied areas (locations or detections), establishment of additional salamanders in one or more areas through translocations, implementation of the Santa Fe National Forest Plan preferred alternative (USFS 2022c, pg. 31-37), and development of new natural resource management techniques over time. These additional conservation actions/measures will be based on adaptive management.

For the scenarios, we assume that implemented conservation actions/measures (monitoring of newly identified occupied areas (locations or detections), translocating salamanders, and natural resource management) will be successful and result in positive outcomes for the salamander or its habitat. Monitoring actions/measures are currently used to monitor areas (locations or detections) known to be currently occupied and will be implemented in new areas as additional salamanders are detected across the species' range. Monitoring and surveying are expected to continue because of the ongoing conservation efforts by and strong partnerships with federal, state, and academic partners. As stated above (in section 3.2.1 Assumptions and Data Limitations), over the past 2 years (2021-2022) salamanders were detected at 2 of 39 (5%) and 5 of 74 (7%) historically occupied sites surveyed. Although this information is preliminary and based on two years of effort, we expect survey efforts to continue and assume a similar detection rate over the next 10 years (see section 6.2.1 Resiliency Factor: Future Recruitment, below, for additional information). Continued monitoring and survey efforts will increase our understanding of the species' biology and distribution and may result in higher detection rates in the future. Lack of structured survey efforts range-wide has obscured our understanding of the Jemez Mountains salamander's true distribution; therefore, we assume that increased survey effort will result in additional salamander detections across the species' range and positively influence our future understanding of recruitment condition.

Conservation actions for the species do occur. For example, in response to the rerouting of highway 126, Jemez Mountains salamanders were translocated to a different site (Watson 2007, entire), and subsequent monitoring has documented salamanders there, which suggests that translocation may be a viable conservation tool (USFWS 2024, entire). Additional information, however, is needed before we understand the variables that may contribute to a successful translocation event.

We assume that high elevations are effective at buffering favorable and moderately favorable habitat from some of the impacts of future projected warming and drying. We recognize that this assumption may result in somewhat optimistic projections of future resiliency in some subunits compared to subunits where lower elevation areas are more prevalent (eastern portions of the species' range). Additionally, conservation measures are not implemented consistently across the species' range. Activities to reduce wildfire risk, such as mechanical thinning and prescribed burns, are more likely to occur in areas or subunits that have not experienced recent widespread wildfires, whereas activities such as planting will occur in areas already impacted by wildfire, in need of forest regeneration, and where and when proper environmental conditions exist. Our assumption that conservation measures are implemented and successful positively influences the future resiliency of some subunits by protecting and growing habitat, effectively mitigating some of the impacts of worsening climatic conditions. Because our assumptions generally improve salamander abundance, distribution and habitat, deviation from our assumptions is likely to negatively influence projected future conditions.

6.2.1 Resiliency Factor: Future Recruitment

To model plausible future recruitment for the Jemez Mountains salamander, we assumed equal survey effort across the species' range, regardless of where historical detections occurred, and applied an equal rate of detection during surveys across all potential habitat (favorable, moderately favorable, and less favorable: section 8 Appendix). As more positive detections are identified over time, we expect that there is less time to survey new sites and that some sites are more difficult to access because of rough terrain and distance from roads. Therefore, although we assume that an average of 30 historically occupied sites with unknown current occupancy are surveyed in years 1-10, we expect the number of average annual surveys conducted to decline by 10 percent of the original estimate (3 sites) every decade. For example, in years 1-10, 30 surveys on average are conducted annually; in years 11-20, 27 surveys on average are conducted annually; and in years 21-30, 24 surveys on average are conducted annually. Because our ability to conduct surveys and detect salamanders is influenced by a number of factors (e.g., funding, weather, etc.) these assumptions are plausible but may also be overly optimistic.

Global surface temperatures are expected to increase under all future scenarios (IPCC 2021, p. 14). Given modeled future climate, including warming temperatures and increased drought, we anticipate that our ability to detect Jemez Mountains salamanders will be affected as the salamanders spend more time below ground to escape adverse conditions; additionally, survival and fecundity may be reduced as time above ground (for foraging and breeding) may be limited, or a shift between timing of occurrence above ground and resource availability could occur. Recent efforts to detect Jemez Mountains salamanders at sites that were historically occupied but not recently surveyed have yielded detections at 6 percent of historically occupied sites surveyed (of 113 sites, total, surveyed in 2021 and 2022; N. Karraker, pers. comm.). Given the uncertainty about the initial rate of temperature change and divergence between future scenarios, for this SSA we held the detection rate during years 1 to 10 constant at 6 percent for all 3 future scenarios. We assume that detection rates decline after 10 years to 4 percent and 2 percent annually in Scenarios 2 and 3, respectively. We evaluated historical detections (buffered by 43 m) in GIS to assess the current underlying habitat used by Jemez Mountains salamanders at those sites. Less favorable habitat was 100 percent of underlying habitat in 17 percent of historical detections and less favorable habitat was at least 50 percent of underlying habitat in 42 percent of historical detections. We assume that less favorable habitat is unlikely or unable to support Jemez Mountains salamanders in the future under increasing climatic stressors; therefore, the total number of detections modeled was reduced by 17 percent in Scenario 2 and 42 percent in Scenario 3. We also assume that all modeled detections meet the definition of a high condition location. To estimate the number of modeled locations per subunit, the total number of modeled locations was multiplied by the percent of total potential habitat within the subunit compared to all potential habitat across the species' range.

For locations that currently meet the definition of high or moderate condition, we applied the following logic to determine their future fate. No change from current condition in Scenario 1. If habitat within the location is between 50 and 100 percent less favorable habitat, the future condition dropped one condition category from its current condition under Scenario 2 and two condition categories under Scenario 3. If habitat within the location is between 25 and 50 percent less favorable habitat, the future condition dropped one condition category from its current condition in Scenario 3. Model results for all scenarios are provided in Table 6.1, and future recruitment conditions are provided in Table 6.2. We recognize that modeled future recruitment incorporates several assumptions, which provides a mechanism to compare potential differences in future recruitment across the species' range, if applied assumptions were to occur. Such comparisons are useful to assess plausible future scenarios for subunits, relative to one another, but cannot be interpreted to represent true future recruitment.

Table 6.1. Number of modeled locations that meet definitions (Table 4.1) to contribute to high:moderate:low condition.

Unit:subunit	Scenario 1 at 15 years	Scenario 2 at 100 years	Scenario 3 at 100 years
Forest North:1	2:0:0	5:0:0	2:0:0
Forest North:2	1:0:0	2:0:0	1:0:0
Forest North:3	0:0:0	1:0:0	0:0:0
Forest North:4	1:0:0	3:0:0	1:0:0
Forest North:5	1:0:0	2:0:0	1:0:0
Forest North:6	1:0:0	3:0:0	1:0:0
Forest North:7	1:0:0	2:0:0	1:0:0
Laboratory:1	0:2:0	0:2:0	0:0:2
Laboratory:2	0:1:0	1:0:1	0:0:0
Laboratory:3	1:0:0	1:0:0	0:1:0
Laboratory:4	1:1:0	1:0:1	0:1:1
Laboratory:5	0:0:0	1:0:0	0:0:0
Laboratory:6	0:1:0	0:0:1	0:0:0
Monument:1	1:0:0	3:0:0	1:0:0
Monument:2	0:0:0	0:0:0	0:0:0
Monument:3	0:0:0	0:0:0	0:0:0
Monument:4	2:0:0	2:0:0	0:2:0
Monument:5	1:1:0	1:0:1	0:1:0
Monument:6	0:0:0	0:0:0	0:0:0
Monument:7	1:0:0	2:0:0	1:0:0
Forest West:1	3:2:0	6:1:1	2:1:1
Forest West:2	5:3:0	7:3:0	1:4:3
Forest West:3	3:0:0	4:1:0	2:0:1
Forest West:4	1:0:0	3:0:0	1:0:0
Forest West:5	1:0:0	3:0:0	1:0:0
Forest West:6	0:0:0	1:0:0	0:0:0
Forest West:7	6:0:0	7:0:0	1:5:0
Preserve:1	1:1:0	2:0:1	1:0:0
Preserve:2	1:0:0	3:0:0	1:0:0
Preserve:3	3:1:0	2:2:1	1:0:2
Preserve:4	0:0:0	1:0:0	0:0:0
Preserve:5	1:0:0	2:0:0	1:0:0
Preserve:6	1:0:0	1:0:0	1:0:0
Preserve:7	1:0:0	1:0:0	1:0:0

Table 6.2. Current recruitment condition and modeled future recruitment conditions.

Unit:subunit	Current Recruitment	Scenario 1: 15 Years	Scenario 2: 100 Years	Scenario 3: 100 Years
Forest North:1	Very Low/Unknown	Moderate	High	Moderate
Forest North:2	Very Low/Unknown	Low	Moderate	Low
Forest North:3	Very Low/Unknown	Very Low/Unknown	Low	Very Low/Unknown
Forest North:4	Very Low/Unknown	Low	High	Low
Forest North:5	Very Low/Unknown	Low	Moderate	Low
Forest North:6	Very Low/Unknown	Low	High	Low
Forest North:7	Very Low/Unknown	Low	Moderate	Low
Laboratory:1	Moderate	Moderate	Moderate	Low
Laboratory:2	Moderate	Moderate	Moderate	Very Low/Unknown
Laboratory:3	Low	Low	Low	Low
Laboratory:4	Moderate	Moderate	Low	Low
Laboratory:5	Low	Very Low/Unknown	Low	Very Low/Unknown
Laboratory:6	Low	Low	Low	Very Low/Unknown
Monument:1	Low	Low	High	Low
Monument:2	Very Low/Unknown	Very Low/Unknown	Very Low/Unknown	Very Low/Unknown
Monument:3	Very Low/Unknown	Very Low/Unknown	Very Low/Unknown	Very Low/Unknown
Monument:4	Moderate	Moderate	Moderate	Moderate
Monument:5	Moderate	Moderate	Low	Low
Monument:6	Very Low/Unknown	Very Low/Unknown	Very Low/Unknown	Very Low/Unknown
Monument:7	Very Low/Unknown	Low	Moderate	Low
Forest West:1	Moderate	High	High	Moderate
Forest West:2	High	High	High	Moderate
Forest West:3	Low	High	High	Moderate
Forest West:4	Very Low/Unknown	Low	High	Low
Forest West:5	Very Low/Unknown	Low	High	Low
Forest West:6	Very Low/Unknown	Very Low/Unknown	Low	Very Low/Unknown
Forest West:7	High	High	High	Moderate
Preserve:1	Low	Moderate	Moderate	Low
Preserve:2	Very Low/Unknown	Low	High	Low
Preserve:3	High	High	Moderate	Low
Preserve:4	Very Low/Unknown	Very Low/Unknown	Low	Low
Preserve:5	Very Low/Unknown	Low	Moderate	Low
Preserve:6	Very Low/Unknown	Very Low/Unknown-Low	Low	Low
Preserve:7	Very Low/Unknown	Very Low/Unknown-Low	Low	Low

6.2.2 Resiliency Factors: Future Favorable Habitat and Burn

To determine the future Favorable Habitat and future Burn metrics under Future Scenarios 2 and 3, we used U.S. Forest Service Geodata Clearinghouse (USFS 2023, entire) raster layer files to compile future environmental information. This resulted in the SSA team considering a mixture of qualitative and quantitative data.

For Scenario 2, this information included increased moisture deficit (moisture deficit/aridity index; "IMD") and summer (June to August) mean temperature increase ("SMTI"; Figure 6.1). The IMD is classified from low, moderate, moderate/high, to high (Figure 6.1). Some subunits had multiple classifications (e.g., an area within the subunit may be classified as "low" and another area as "moderate"). In these cases, the SSA team determined the subunit's overall IMD based on visual evaluations of the predominant category. The SMTI is classified from 2.4 to 3.1 °C; (increasing by 0.1 °C; Figure 6.1). Both datasets were compiled with climate normal (base date) from 1991 – 2020 and are included under scenario SSP2-4.5 from 2071 – 2100. Results for Scenario 2 IMD and SMTI (Table 6.3**Table 6.3**), as well as anticipated future conservation efforts, for all Jemez Mountains salamander subunits were used by the salamander SSA team to determine the future favorable habitat and future burn conditions metrics under Scenario 2.

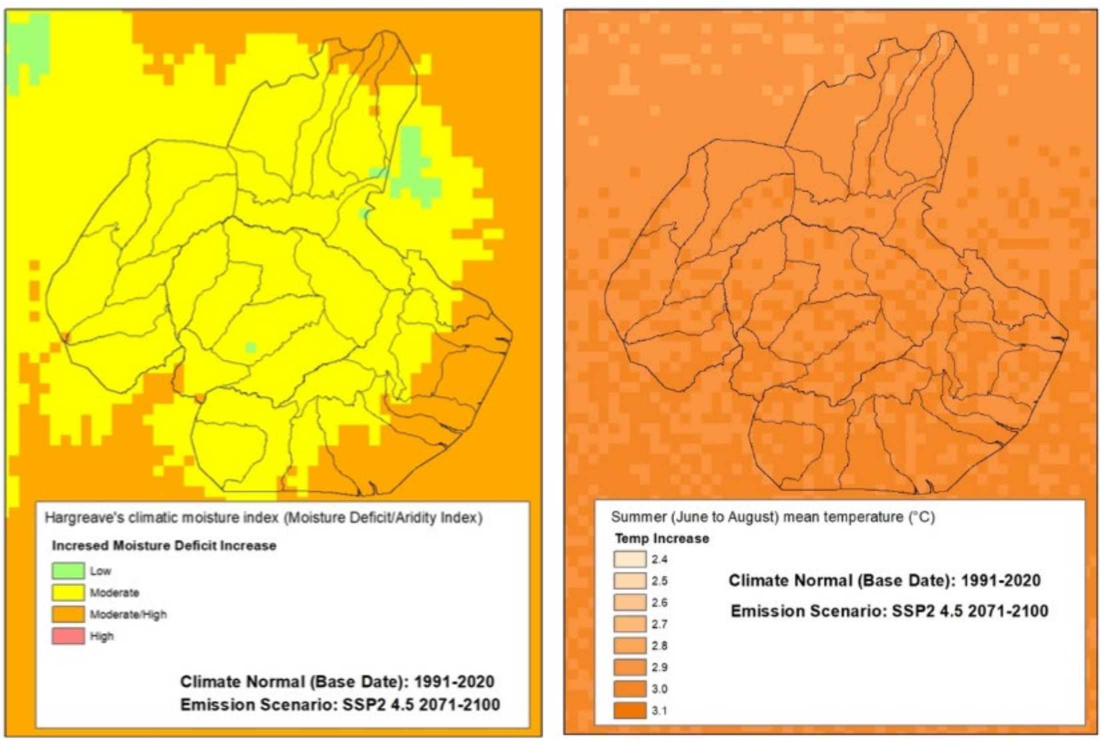

Figure 6.1. Future environmental information including increased moisture deficit (moisture deficit/aridity index; image on left) and summer (June to August) mean temperature increase (image on right) from U.S. Forest Service Geodata Clearinghouse raster layer files. Both datasets were compiled with climate normal (base date) from 1991 – 2020 and are included under scenario SSP2-4.5 from 2071 – 2100.

For Scenario 3, this information also included IMD (for scenario SSP5-8.5) but classified from moderate to very high (Figure 6.2) and SMTI (for scenario SSP5-8.5) but classified from 4.3 to 4.9 °C (increasing by 0.1 °C; Figure 6.2). These datasets were also compiled with climate normal (base date) time periods from 1991 – 2020 and future time periods from 2071 – 2100. Similar to Scenario 2, in cases where a subunit had more than one IMD classification, the SSA team determined the subunit's overall IMD. Scenario 3 also included future environmental information of absolute change snow water equivalent (depth of snow if melted in millimeters on April 1, "ACSWE") and percent change wetting rain days (average number of wetting rain days more than 0.1 inch [2.54 mm] of precipitation from May – Sept., "PCWRD"; Figure 6.3). The ACSWE ranged from no change, -1 to 50 mm, -51 to -100 mm, -101 to -150 mm, -151 to -200 mm, and -201 to -300 mm. The PCWRD ranged from no change/positive change, negative change moderate (-1% to -3%), to negative change highest (-4% to -6%). Both ACSWE and PCWRD datasets used historical (1975 – 2005) and future (2071 – 2090) time periods. Results for Scenario 3 IMD, SMTI, ACSWE, and PCWRD (Table 6.3), as well as predicted conservation efforts, for all Jemez Mountains salamander subunits were used by the salamander SSA team to determine the future favorable habitat and future burn conditions metrics under scenario 5-8.5.

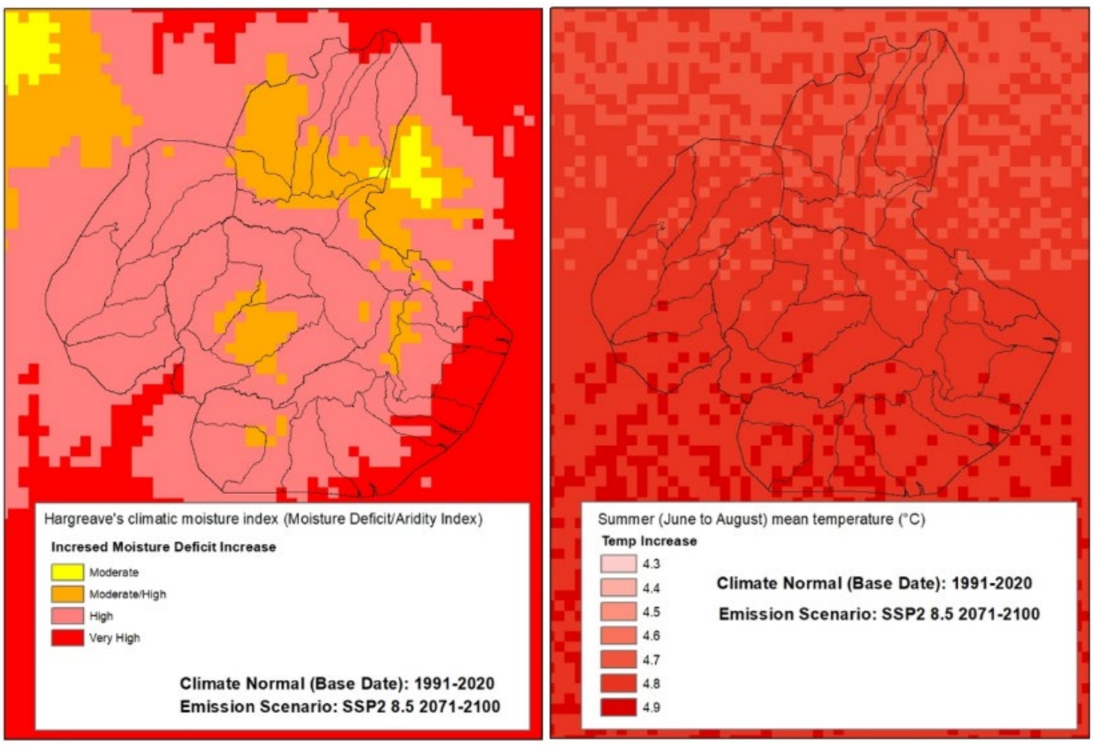

Figure 6.2. Future environmental information including increased moisture deficit (moisture deficit/aridity index; image on left) and summer (June to August) mean temperature increase (image on right) from U.S. Forest Service Geodata Clearinghouse raster layer files. Both datasets were compiled with climate normal (base date) from 1991 – 2020 and are included under scenario SSP5-8.5 from 2071 – 2100.

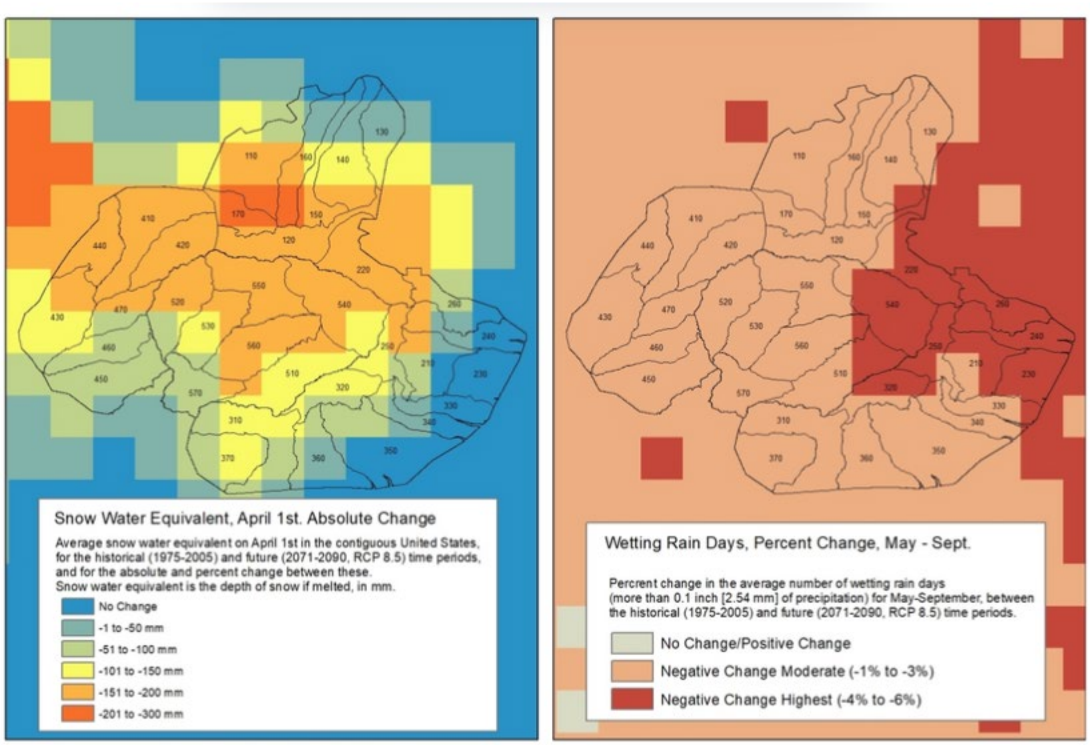

Figure 6.3. Future environmental information including absolute change snow water equivalent (depth of snow if melted in millimeters on April 1; image on left) and percent change wetting rain days (average number of wetting rain days more than 0.1 inch [2.54 mm] of precipitation from May – Sept.; image on right) from U.S. Forest Service Geodata Clearinghouse raster layer files. Both datasets used historical (1975 – 2005) and future (2071 – 2090) time periods and are included under scenario SSP5-8.5.

Table 6.3. Species Status Assessment core team rankings for future increased moisture deficit (moisture deficit/aridity index), summer (June to August) mean temperature increase, absolute change snow water equivalent (depth of snow if melted in millimeters on April 1; image on left) and percent change wetting rain days (average number of wetting rain days more than 0.1 inch [2.54 mm] of precipitation from May – Sept.; image on right) at the for scenario SSP2-4.5 and SSP5-8.5.

Unit:subunit	Moisture Deficit Inc 4.5	Summer Mean Temp 4.5	Moisture Deficit Inc 8.5	Summer Mean Temp 8.5	Snow Water Equivalent Apr. 1st change 8.5	Wet Rain Days % chg. 8.5
Forest North:1	Mod	2.9	Mod/High	4.7	-151 to -200 mm	-Chg Mod
Forest North:2	Mod	2.9	High	4.8	-151 to -200 mm	-Chg Mod
Forest North:3	Mod	2.9	High	4.7	-1 to 50 mm	-Chg Mod
Forest North:4	Mod	2.9	High	4.7	-101 to -150 mm	-Chg Mod
Forest North:5	Mod	2.9	High	4.7	-101 to -150 mm	-Chg Mod
Forest North:6	Mod	2.9	High	4.7	-151 to -200 mm	-Chg Mod
Forest North:7	Mod	2.9	Mod/High	4.7	-201 to -300 mm	-Chg Mod
Laboratory:1	Mod	3	High	4.8	-51 to -100 mm	-Chg High
Laboratory:2	Mod	2.9	High	4.8	-151 to -200 mm	-Chg High
Laboratory:3	Mod/High	3	Very High	4.8	No Change	-Chg High
Laboratory:4	Mod/High	2.9	Very High	4.8	-1 to -50 mm	-Chg High
Laboratory:5	Mod	3	High	4.8	-101 to -150 mm	-Chg High
Laboratory:6	Mod	2.9	High	4.8	-51 to -100 mm	-Chg High
Monument:1	Mod	3	High	4.8	-101 to -150 mm	-Chg Mod
Monument:2	Mod	3	High	4.8	-101 to -150 mm	-Chg High
Monument:3	Mod/High	3	Very High	4.8	No Change	-Chg Mod
Monument:4	Mod/High	3	High	4.8	No Change	-Chg Mod
Monument:5	Mod/High	3.1	High	4.8	No Change	-Chg Mod
Monument:6	Mod	3.1	High	4.8	-1 to -50 mm	-Chg Mod
Monument:7	Mod	3.1	High	4.8	-51 to -100 mm	-Chg Mod
Forest West:1	Mod	2.9	High	4.8	-151 to -200 mm	-Chg Mod
Forest West:2	Mod	3	High	4.8	-151 to -200 mm	-Chg Mod
Forest West:3	Mod	3	High	4.8	-101 to -150 mm	-Chg Mod
Forest West:4	Mod	2.9	High	4.8	-151 to -200 mm	-Chg Mod
Forest West:5	Mod	3	High	4.8	-51 to -100 mm	-Chg Mod
Forest West:6	Mod	3	High	4.8	-51 to -100 mm	-Chg Mod
Forest West:7	Mod	3	High	4.8	-51 to -100 mm	-Chg Mod
Preserve:1	Mod	3	High	4.8	-101 to -150 mm	-Chg Mod
Preserve:2	Mod	2.9	High	4.8	-151 to -200 mm	-Chg Mod
Preserve:3	Mod	3	High	4.8	-101 to -150 mm	-Chg Mod
Preserve:4	Mod	3	High	4.8	-151 to -200 mm	-Chg High
Preserve:5	Mod	2.9	High	4.8	-151 to -200 mm	-Chg Mod
Preserve:6	Mod	3	Mod/High	4.8	-151 to -200 mm	-Chg Mod
Preserve:7	Mod	3	High	4.8	-51 to -100 mm	-Chg Mod

6.3 Future Scenario Descriptions

Scenario 1: Continuation of Current Stressor Trends and Current Conservation Actions

In Scenario 1 we assume future climatic conditions align with the IPCC's SSP1-2.6 model which approximates a 1.5 °C increase in global temperature in the next 10 – 15 years (IPCC 2021, p. 14). Under this scenario, surveying of currently occupied subunits (Forest West 2 and 7, and Preserve 3) will continue, partners will also survey historical and new sites, current forest management practices (thinning and prescribed burning) will continue, but no new forest management activities or additional conservation measures will be implemented. Monitoring effort of three currently known populations may decrease to some degree under this scenario, but we expect some level of continued monitoring effort at these areas. Environmental changes, including drought and wildfire, and human development stressors, including disease, fire management, forest management, and wildfire, will continue to impact Jemez Mountains salamander populations and their habitat. Under this scenario, it is expected that the continued survey effort (monitoring of three currently known populations, and presence or absence surveys of historical and new locations within the range) will result in continued captures of salamanders at the currently known population sites and sporadic captures at other locations within the salamander's range (see section 6.2 Conservation Actions, Future Resiliency Factors, and Assumptions, above). As discussed previously (in chapters 2 SPECIES ECOLOGY AND NEEDS and 3 DISTRIBUTION, above), detection of this salamander is difficult, so surveys in some subunits may not yield any salamander detections. Because of the continuation of the SSP1- 2.6 climate model, it is expected that habitat conditions will remain relatively constant; however, one or more high-intensity wildfires may impact subunits within the salamander's range in the next 10-15 years under this scenario, which could influence salamander suitable habitat and populations.

Scenario 2: Moderate Stressor Increase (SSP2-4.5) and Increase in Conservation Actions and *Scenario 3*: Greater Stressor Increase (SSP5-8.5) and Increase in Conservation Actions

In Scenarios 2 and 3 we assume future climatic conditions align with the IPCC's SSP2-4.5 and SSP5-8.5 models, which approximate a 2.7° C and 4.4° C (respectively) increase in global temperature in the next 60 – 100 years (IPCC 2021, p. 14). Under these scenarios, surveying of currently occupied subunits (Forest West 2 and 7 and Preserve 3) will continue but likely with less effort, partners will also continue to survey historical and new sites, and current forest management practices (thinning and prescribed burning) will continue. It is likely that new forest management activities and additional conservation measures (based on adaptive management) will be implemented. Environmental changes, including drought and wildfire, and human development stressors, including disease, fire management, forest management, and wildfire will continue to impact Jemez Mountains salamander populations and their habitat. Under these scenarios, it is expected that the continued survey effort (monitoring of three currently known populations, and presence or absence surveys of historical and new locations within the range) will result in continued captures of salamanders at the currently known population sites and sporadic captures at other locations within the salamander's range; however, as impacts from environmental changes and human development stressors increase under these scenarios, it is likely that fewer salamander detections will occur, as described in section 6.2.1 Resiliency Factor: Future Recruitment. As discussed previously (in chapters 2 SPECIES ECOLOGY AND NEEDS and 3 DISTRIBUTION, above), detection of this salamander is difficult, so surveys in some subunits may not yield any salamander detections. There is some uncertainty with future climatic conditions for the SSP2-4.5 and SSP5-8.5 models; however, it is expected that habitat conditions within the Jemez Mountains will change. Under both scenarios, we expect temperatures to increase at the lower elevations of the Jemez Mountains salamander's range (but changes at all elevations are possible); thus, salamander habitat conditions at lower elevation levels (including vegetation class, canopy cover, relative humidity, soil temperatures etc.) will likely become less suitable. This may lead to dispersal of salamander populations to higher elevations or extirpation of populations due to the limited dispersal capability of the species. We also expect that one or more high-intensity wildfires may impact subunits within the salamander's range in the next 50-100 years under these scenarios, which could influence salamander populations. While both scenarios will likely result in less suitable habitat conditions for salamanders, we expect to see greater impacts from environmental changes and human development stressors on salamander populations and habitat for the SSP5-8.5 model relative to the SSP2-4.5 model.

6.4 Future Resiliency

6.4.1 *Scenario 1*: Continuation of Current Trends for the Next 15 Years

Scenario 1 was constructed to provide insight on the potential for current management activities to offset changing conditions in the near-term (10-15 years) for the salamander. We assume in this scenario that measures to mitigate the risk of large-scale wildfires are prioritized in the most vulnerable and valuable habitats and are relatively successful in mitigating the risk of high-severity wildfire where implemented. Although increased warming and drought occur, it was not thought sufficient to result in large scale reductions of habitat at high elevations, such that sufficient habitat will remain over the next 10-15 years to support salamanders. Increased survey effort over this timeframe would result in increased detections of salamanders, resulting in some subunits increasing in overall condition from current levels. Current conditions for each unit referenced below are found in Table 4.7.

Forest North Unit

Under Scenario 1, most of the Forest North subunits are expected to remain similar to current conditions of moderate to low with regards to overall conditions (recruitment, favorable habitat, and burn), except for subunits 1 and 2 which transition from low to moderate (Figure 6.4). Recruitment conditions are currently very low/unknown for all subunits within the Unit since there has been little to no survey effort. Future survey efforts may yield salamander locations; thus, recruitment (in all subunits except for 3) will likely increase (Table 6.4). Favorable habitat within the Unit currently varies between subunits from very low to high (majority are moderate or high), and this variety is expected to remain, although individual subunits may increase or decrease depending on amount of potential salamander habitat ranked as favorable in the subunit. Burn in the Unit and within all subunits is currently ranked as high and is expected to stay at that level for this scenario.

Laboratory Unit

Under Scenario 1, the Laboratory subunits are expected to remain similar to current conditions of low with regards to overall conditions (recruitment, favorable habitat, and burn) (Table 6.4; Figure 6.4). Recruitment conditions are currently moderate to low for all subunits within the Unit since there has been limited survey effort in this Unit. Future survey efforts may yield additional salamander locations; however, recruitment is not expected to change from current conditions. Favorable habitat within the Unit currently varies between subunits from low to very low (five out of six subunits) and this variety is expected to remain, although individual subunits may increase or decrease depending on amount of potential salamander habitat ranked as favorable in the subunit. Burn in the Unit and within all subunits is currently ranked as high (one of six subunits) and low (five of six subunits) based on the amount of the subunit burned by moderate- to high-severity fire. Subunit burn conditions are expected to stay at the current levels for this scenario.

Monument Unit

Under Scenario 1, all of the Monument subunits are expected to remain similar to current conditions of low or very low/unknown with regards to overall conditions (recruitment, favorable habitat, and burn) (Table 6.4; Figure 6.4). Recruitment conditions are currently moderate to very low/unknown for all subunits within the Unit since there has been limited survey effort in this Unit. Future survey efforts may yield additional salamander locations; thus, recruitment (in subunit 7) will likely increase (Table 6.4). Favorable habitat within the Unit currently varies between subunits from low (three of seven subunits) to very low (four of seven subunits) and this variety is expected to remain, although individual subunits may increase or decrease depending on amount of potential salamander habitat ranked as favorable in the subunit. Burn in the Unit and within all subunits is currently ranked as moderate (two of seven subunits), low (four of seven subunits), and very low (one of seven subunits) based on the amount of the subunit burned by moderate- to high-severity fire. Subunit burn conditions are expected to stay at the current levels for this scenario.

Forest West Unit

Under Scenario 1, most of the Forest West subunits are expected to remain similar to current conditions of high to very low/unknown with regards to overall conditions (recruitment, favorable habitat, and burn), except for subunit 3 which transitions from low to moderate (Table 6.4; Figure 6.4). Recruitment conditions are currently high (two of seven subunits), moderate (one of seven subunits), low (one of seven subunits), and very low/unknown (three of seven subunits) within the Unit, and there has been recent survey effort in this Unit (in subunits 2 and 7). Future survey efforts may yield additional salamander locations; thus, recruitment (in subunits 1, 3, 4, and 5) will likely increase. Favorable habitat within the Unit currently varies between subunits from high (three of seven subunits), low (one of seven subunits), to very low (three of seven subunits), and this variety is expected to remain, although individual subunits may increase or decrease depending on amount of potential salamander habitat ranked as favorable in the subunit. Burn in the Unit and within all subunits is currently ranked as high (six of seven subunits) and low (one of seven subunits) based on the amount of the subunit burned by moderate- to high-severity fire. Subunit burn conditions are expected to stay at the current levels for this scenario.

Preserve Unit

Under Scenario 1, all of the Preserve subunits are expected to remain similar to current conditions of moderate to low with regards to overall conditions (recruitment, favorable habitat, and burn) (Table 6.4; Figure 6.4). Recruitment conditions are currently moderate (one of seven subunits), low (one of seven subunits), and very low/unknown (five of seven subunits) within the Unit, and there has been recent survey effort in this Unit (in subunits 1, 3, and 6). Future survey efforts may yield additional salamander locations; thus, recruitment (in all subunits except for subunit 4) will likely increase. Favorable habitat within the Unit currently varies between subunits from high (two of seven subunits), moderate (one of seven subunits), low (two of seven subunits), to very low (two of seven subunits), and this variety is expected to remain, although individual subunits may increase or decrease depending on amount of potential salamander habitat ranked as favorable in the subunit. Burn in the Unit and within all subunits is currently ranked as high (five of seven subunits), moderate (one of seven subunits), and low (one of seven subunits) based on the amount of the subunit burned by moderate- to high-severity fire. Subunit burn conditions are expected to stay at the current levels for this scenario.

Table 6.4. Jemez Mountains salamander subunit conditions under Scenario 1.

Unit:subunit	Future Recruitment	Future Favorable Habitat	Future Burn	Overall Condition
Forest North:1	Moderate	Low	High	Moderate
Forest North:2	Low	Low	High	Moderate
Forest North:3	Very Low/ Unknown	Very Low	High	Low
Forest North:4	Low	Moderate	High	Moderate
Forest North:5	Low	Moderate	High	Moderate
Forest North:6	Low	Moderate	High	Moderate
Forest North:7	Low	High	High	Moderate
Laboratory:1	Moderate	Very Low	Low	Low
Laboratory:2	Moderate	Low	Low	Low
Laboratory:3	Low	Very Low	High	Low
Laboratory:4	Moderate	Very Low	Low	Low
Laboratory:5	Low	Very Low	Low	Low
Laboratory:6	Low	Very Low	Low	Low
Monument:1	Low	Low	Low	Low
Monument:2	Very Low/ Unknown	Low	Very Low	Very Low
Monument:3	Very Low/ Unknown	Very Low	Moderate	Low
Monument:4	Moderate	Very Low	Low	Low
Monument:5	Moderate	Very Low	Low	Low
Monument:6	Very Low/ Unknown	Very Low	Low	Very Low
Monument:7	Low	Low	Moderate	Low
Forest West:1	High	High	High	High
Forest West:2	High	High	High	High
Forest West:3	High	Very Low	High	Moderate
Forest West:4	Low	High	High	Moderate
Forest West:5	Low	Very Low	High	Low
Forest West:6	Very Low/ Unknown	Very Low	Low	Very Low
Forest West:7	High	Low	High	Moderate
Preserve:1	Moderate	Moderate	High	Moderate
Preserve:2	Low	High	High	Moderate
Preserve:3	High	Low	High	Moderate
Preserve:4	Very Low/ Unknown	High	Low	Low
Preserve:5	Low	Very Low	High	Low
Preserve:6	Low	Low	Moderate	Low
Preserve:7	Low	Very Low	High	Low

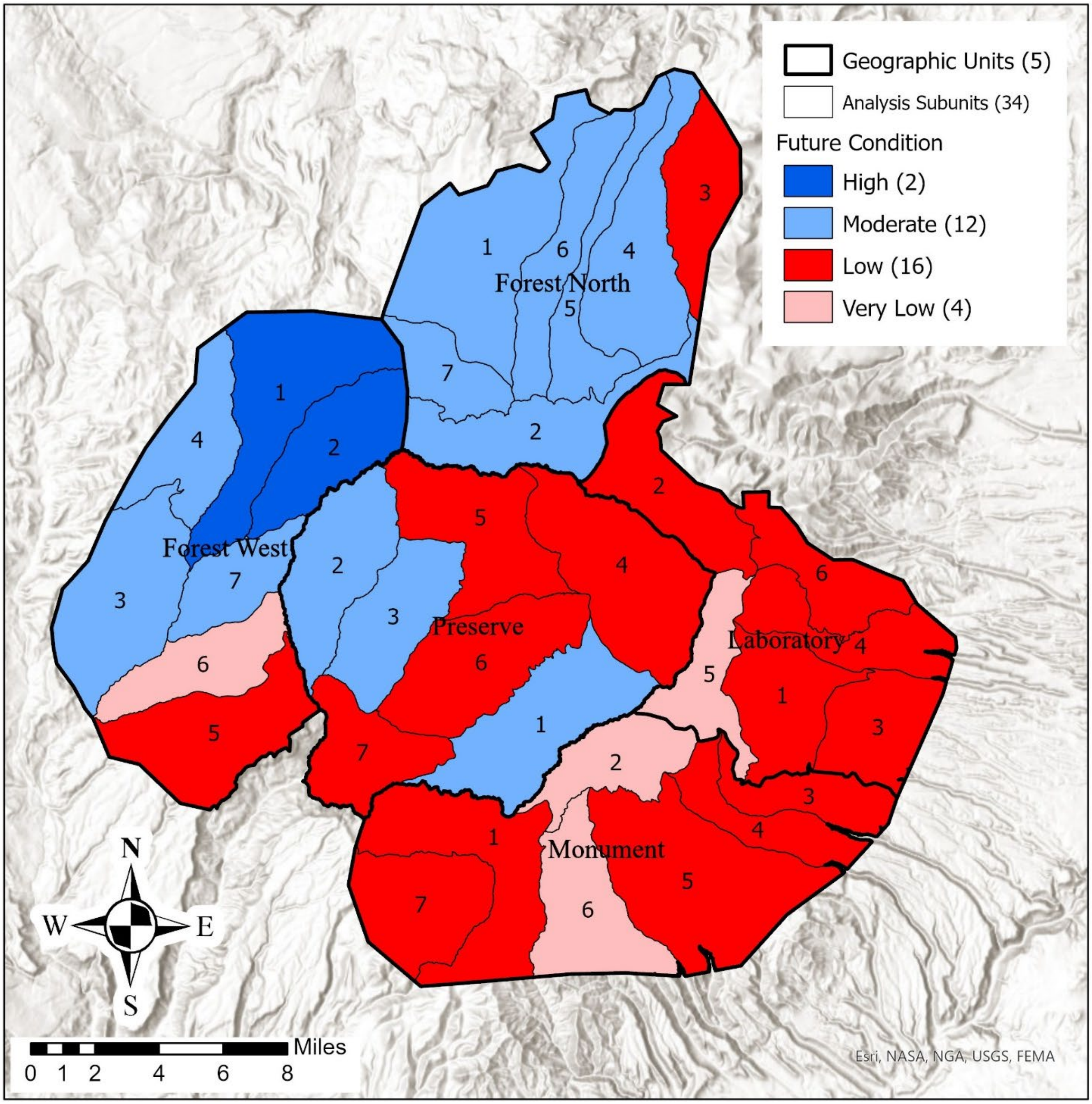

Figure 6.4. Projected future overall resiliency condition in 15 years under Scenario 1.

6.4.2 *Scenario 2*: Moderate Stressor Increase and Increase in Conservation Actions

As stated in section 6.1 Future Scenario Assumptions, calculations for Scenario 2 (SSP2-4.5 for 60-100 years) IMD (moisture deficit) and SMTI (increased temperature) for all Jemez Mountains salamander subunits were determined and used by the salamander SSA team to help assign the future favorable habitat and future burn conditions (Table 6.3**Table 6.3**). This information, along with the modeled future recruitment (from section 6.1 Future Scenario Assumptions), was used to determine the overall future condition for each subunit. Future conditions, organized by Unit, for Scenario 2 are discussed below. Current conditions for each unit referenced below are found in Table 4.7.

Forest North Unit

Under Scenario 2, the Forest North Unit is expected to remain in similar conditions to current conditions with regard to overall conditions; two subunits increase in condition, six subunits are in moderate and one in low overall condition. Overall future condition is predicted to remain the same as current overall condition for Forest North subunits 3, 4, 5, 6, and 7 (all low or moderate; Table 6.5, Figure 6.5). Overall future condition in Forest North subunits 1 and 2 are expected to change from low (current) to moderate (future; Table 6.5, Figure 6.5).

Forest North subunits 1, 4, and 6

Currently Forest North subunits 1, 4, and 6 are in very low/unknown condition for recruitment due to lack of historical survey efforts. Implementation of systematic surveys over the next 100 years is predicted to increase future recruitment condition to high in all subunits. The amount of favorable habitat compared to all potential habitat is expected to decrease from moderate to low (Forest North subunits 4 and 6) and remain in low (Forest North subunit 1) condition for these three subunits under the SSP2-4.5 predicted changes in climate. Although declines in favorable habitat of up to 5 percent from current conditions are concerning, 10-15 percent of potential habitat would still be ranked as favorable habitat, and conservation measures to protect habitat occupied by salamanders are expected to be successful. Burn condition is expected to decline from high condition to moderate condition for Forest North subunits 1, 4, and 6. Forest and fuels management are expected to reduce but not eliminate wildfire risk; therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Under Scenario 2, given worsening climate conditions and implementation of conservation measures, Forest North subunits 1, 4, and 6 are expected to be in overall moderate condition.

Forest North subunits 2, 5, and 7

Currently Forest North subunits 2, 5, and 7 are in very low/unknown condition for recruitment due to lack of historical survey efforts. Implementation of systematic surveys over the next 100 years is predicted to increase future recruitment condition in those subunits to moderate. The amount of favorable habitat compared to all potential habitat is expected to decrease from high to low (Forest North subunit 7), moderate to low (Forest North subunit 5), or remain in low condition (Forest North subunit 2) under the SSP2-4.5 predicted changes in climate. Although a decline of 5-10 percent in favorable habitat from current conditions is not ideal, 10-15 percent of potential habitat would still be ranked as favorable habitat, and conservation measures to protect habitat occupied by salamanders are expected to be successful. Burn condition is expected to decline from high condition to moderate condition for these subunits. Forest and fuels management are expected to reduce but not eliminate wildfire risk; therefore, we expect wildfires to occur but not at the scale seen over the past two decades.

Under Scenario 2, given worsening climate conditions and implementation of conservation measures, Forest North subunit 7 is expected to remain in overall moderate condition.

Forest North subunit 3

Currently Forest North subunit 3 is in very low/unknown condition for recruitment due to lack of historical survey efforts. Implementation of systematic surveys over the next 100 years is predicted to increase future recruitment condition to low. The amount of favorable habitat compared to all potential habitat is expected to remain in very low condition under the SSP2-4.5 predicted changes in climate. Currently, 4.6 percent of potential habitat within Forest North subunit 3 is ranked as favorable habitat (Table 4.5), therefore, given the 5-10 percent loss of favorable habitat expected in other subunits within the Forest North Unit, it is reasonable to assume loss of all favorable habitat within Forest North subunit 3. Therefore, conservation measures to protect all habitat occupied by salamanders and any potential remaining favorable habitat would be necessary. Burn condition is expected to decline from high condition to moderate condition. Forest and fuels management are expected to reduce but not eliminate wildfire risk; therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Under Scenario 2, given worsening climate conditions and implementation of conservation measures, Forest North subunit 3 is expected to remain in overall low condition.

Laboratory Unit

Under Scenario 2, the Laboratory Unit is expected to remain similar to current conditions with regard to overall conditions; two subunits change condition, resulting in four subunits in low and two in very low overall condition. Overall future condition is predicted to remain the same as current overall condition for Laboratory subunits 1, 2, 3, and 5 (all low; Table 6.5, Figure 6.5). Overall future conditions in Laboratory subunits 4 and 6 are expected to change from low (current) to very low (future; Table 6.5, Figure 6.5).

Laboratory subunits 3 and 5

Currently Laboratory subunits 3 and 5 are in low condition for recruitment due to inconsistent historical and recent survey efforts within the Laboratory Unit. Future recruitment is predicted to remain the same for Laboratory subunits 3 and 5. Implementation of systematic surveys over the next 100 years is unlikely to yield multiple detections in these two subunits because wildfires have severely impacted much of the forested habitat (Figure 5.2). Forest regeneration is a slow process (Stevens-Rumann and Morgan 2019, p. 11) and is needed to replace the impacted forested habitat before regenerated habitat is expected to support salamander persistence. Laboratory subunit 3 is comprised primarily of less favorable habitat in lower elevations, which is less likely to support salamanders under worsening climatic conditions predicted in SSP2-4.5. The amount of favorable habitat compared to all potential habitat is expected to remain in very low (Laboratory subunit 3) and increase from very low to low (Laboratory subunit 5) condition under the SSP2-4.5 predicted changes in climate. Laboratory subunit 5 is comprised of some of the highest-elevation areas within the Laboratory Unit, which is predicted to be less impacted in terms of rising temperatures and increased aridity (Figure 6.1) than adjacent subunits. Therefore, we expect Laboratory subunit 5 to maintain or increase from current favorable habitat. Laboratory subunit 3 is comprised primarily of less favorable habitat and the lowest-elevations areas within the Laboratory Unit, which is predicted to be more impacted in terms of rising temperatures and increased aridity (Figure 6.1). It contains less than 200 acres (81 ha) of favorable habitat, and it is reasonable to assume loss of all favorable habitat within Laboratory subunit 3. Burn condition is expected to decline from low to very low condition for Laboratory subunit 5, and from high to moderate condition for Laboratory subunit 3. Forest and fuels management can reduce but not eliminate wildfire risk in remaining unburned forested habitats and manage future wildlife risk during forest regeneration processes. Therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Under Scenario 2, given worsening climate conditions and implementation of conservation measures, Laboratory subunits 3 and 5 are expected to remain in overall low condition.

Laboratory subunit 1 and 2

Laboratory subunits 1 and 2 are predicted to remain in moderate condition for recruitment because underlying habitat of current salamander locations suggests a high probability of persistence at those locations. Implementation of systematic surveys over the next 100 years is unlikely to yield additional detections because wildfires have severely impacted much of the forested habitat (Figure 5.2). Forest regeneration is a slow process (Stevens-Rumann and Morgan 2019, p. 11) and is needed to replace the impacted forested habitat before regenerated habitat is expected to support salamander persistence. The amount of favorable habitat compared to all potential habitat is expected to increase from very low to low (Laboratory subunit 1) and to remain in low (Laboratory subunit 2) condition under the SSP2-4.5 predicted changes in climate. Laboratory subunit 1 is within a transition of higher- to lower elevation areas and will be differentially impacted by rising temperatures and increased aridity (Figure 6.1) along its elevational gradient. Laboratory subunit 2 is comprised of some of the highest-elevation areas within the Laboratory Unit, which is predicted to be less impacted in terms of rising temperatures and increased aridity (Figure 6.1) than adjacent subunits. Therefore, we expect Laboratory 2 to maintain or increase from current favorable habitat. Burn condition is expected to decline from low to very low condition for Laboratory subunits 1 and 2. Forest and fuels management can reduce but not eliminate wildfire risk in remaining unburned forested habitats and manage future wildlife risk during forest regeneration processes. Therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Under Scenario 2, given worsening climate conditions and implementation of conservation measures, Laboratory subunits 1 and 2 are expected to remain in overall low condition.

Laboratory subunits 4 and 6

Laboratory subunit 4 is predicted to decrease from moderate to low, and Laboratory subunit 6 is predicted to remain in low condition for recruitment because underlying habitat of the current salamander locations is sufficient to maintain low condition. Implementation of systematic surveys over the next 100 years is unlikely to yield additional detections because wildfires have severely impacted much of the forested habitat (Figure 5.2). Although Laboratory subunit 4 is currently in moderate condition, the underlying habitat of the salamander locations suggest one location may decline in condition (see section 6.2.1 Resiliency Factor: Future Recruitment, above), resulting in a future recruitment condition of low. Forest regeneration is a slow process (Stevens-Rumann and Morgan 2019, p. 11) and is needed to replace the impacted forested habitat before regenerated habitat is expected to support salamander persistence. The amount of favorable habitat in these subunits compared to all potential habitat is expected to remain in very low condition under the SSP2-4.5 predicted changes in climate. Laboratory subunits 4 and 6 are comprised primarily of less favorable habitat, within a transition of higher- to lower-elevation areas and will be differentially impacted by rising temperatures and increased aridity (Figure 6.1) along its elevational gradient. They each contain less than 75 acres (30 ha) of favorable habitat, and it is reasonable to assume loss of all favorable habitat within Laboratory subunits 4 and 6. Burn condition is expected to decline from low to very low condition in both subunits. Forest and fuels management can reduce but not eliminate wildfire risk in remaining unburned forested habitats and manage future wildlife risk during forest regeneration processes. Therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Under Scenario 2, given worsening climate conditions and implementation of conservation measures, Laboratory subunits 4 and 6 are expected to be in overall very low condition.

Monument Unit

Under Scenario 2, the Monument Unit is expected to decline slightly compared to current conditions with regard to overall conditions; three subunits change in condition, resulting in one subunit in moderate, two subunits in low, and four in very low overall condition. Overall future condition is predicted to remain the same as current overall condition for Monument subunits 2, 4, 6, and 7 (low for 4 and 7, very low for 2 and 6; Table 6.5, Figure 6.5). Overall future condition in Monument subunit 1 is expected to increase from low to moderate and to decrease from low to very low in Monument subunits 3 and 5 (Table 6.5, Figure 6.5).

Monument subunit 1

Monument subunit 1 is predicted to increase from low to high condition for recruitment. The increase in future recruitment is a result of the implementation of systematic surveys over the next 100 years, and this subunit has the most favorable and potential habitat (within the Monument Unit, Table 4.5) at higher elevations, which provides some level of resiliency to worsening climatic conditions. The underlying habitat of the current salamander locations suggests we will retain those locations in moderate condition (see section 6.2.1 Resiliency Factor: Future Recruitment, above). The amount of favorable habitat compared to all potential habitat is expected to increase to moderate condition under the SSP2-4.5 predicted changes in climate. Monument subunit 1 contains over 2,000 acres (809 ha) of favorable and moderately favorable habitat in higher-elevation areas, which are expected to be less impacted by rising aridity than less favorable habitat in lower-elevation areas. Burn condition is expected to decline from low to very low condition. Forest and fuels management can reduce but not eliminate wildfire risk in remaining unburned forested habitats and manage future wildlife risk during forest regeneration processes. Therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Further, forest regeneration is a slow process (Stevens-Rumann and Morgan 2019, p. 11) and is needed to replace the impacted forested habitat before regenerated habitat is expected to support salamander persistence. Under Scenario 2, given worsening climate conditions and implementation of conservation measures, Monument subunit 1 is expected to be in overall moderate condition.

Monument subunits 4 and 7

Monument subunits 4 and 7 are predicted to be in moderate condition for recruitment. The increase in future recruitment from very low/unknown to moderate (for Monument subunit 7) is a result of the implementation of systematic surveys over the next 100 years. Monument subunit 7 has the second most favorable and potential habitat (within the Monument Unit, Table 4.5) at higher elevations, which provides some level of resiliency to worsening climatic conditions. Monument subunit 4 is within a transition of higher to lower elevation areas and will be differentially impacted by rising temperatures and increased aridity (Figure 6.1) along its elevational gradient. However, the underlying habitat of the current salamander locations suggests we will retain those locations and moderate condition (see section 6.2.1 Resiliency Factor: Future Recruitment, above). The amount of favorable habitat compared to all potential habitat is expected to increase from very low to low (Monument subunit 4) and remain in low (Monument subunit 7) condition under the SSP2-4.5 predicted changes in climate. The change in condition of Monument subunit 4 is due to the previously described elevational transition and temperature and aridity changes. Although Monument subunit 7 contains just over 2,000 acres (809 ha) of moderately favorable and favorable habitat in higher-elevation areas, future projected increases in aridity combined with a greater increase in temperature (Figure 6.1) compared to Monument subunit 1 suggests Monument subunit 7 is slightly less resilient than Monument subunit 1. Burn condition is expected to decline from moderate to low (Monument subunit 7) and from low to very low (Monument subunit 4) condition. Forest and fuels management can reduce but not eliminate wildfire risk in remaining unburned forested habitats and manage future wildlife risk during forest regeneration processes. Therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Further, forest regeneration is a slow process (Stevens-Rumann and Morgan 2019, p. 11) and is needed to replace the impacted forested habitat before regenerated habitat is expected to support salamander persistence. Under Scenario 2, given worsening climate conditions and implementation of conservation measures, Monument subunits 4 and 7 are expected to remain in overall low condition.

Monument subunits 2 and 3

Monument subunits 2 and 3 are predicted to remain in very low condition for recruitment. Implementation of systematic surveys over the next 100 years is unlikely to yield multiple detections in these subunits because wildfires have severely impacted much of the forested habitat (Figure 5.2). Additionally, Monument subunit 3 is comprised primarily of less favorable habitat in lower elevations, which is less likely to support salamanders under worsening climatic conditions predicted in SSP2-4.5. The amount of favorable habitat compared to all potential habitat is expected to remain in low (Monument subunit 2) and very low (Monument subunit 3) condition under the SSP2-4.5 predicted changes in climate. Monument subunit 2 is in higher elevations relative to adjacent subunits in the Monument Unit, which provides some level of resiliency to worsening climatic conditions and suggests the ability to maintain current levels of favorable habitat. Monument subunit 3 is within a transition of higher- to lower-elevation areas and will be differentially impacted by rising temperatures and increased aridity (Figure 6.1) along its elevational gradient. However, following past wildfire history in Monument subunit 3, there is little remaining potential habitat (~1000 acres [405 ha]) most of which is less favorable habitat and predicted to be more impacted in terms of rising temperatures and increased aridity (Figure 6.1). Currently there are less than 50 acres (20 ha) of favorable habitat remaining, and it is reasonable to assume loss of all favorable habitat within Monument subunit 3. Burn condition is expected to increase from very low to low (Monument subunit 2) and decrease from moderate to low condition (Monument subunit 3). Forest and fuels management can reduce but not eliminate wildfire risk in remaining unburned forested habitats and manage future wildlife risk during forest regeneration processes. Therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Further, forest regeneration is a slow process (Stevens-Rumann and Morgan 2019, p. 11) and is needed to replace the impacted forested habitat before regenerated habitat is expected to support salamander persistence. Additionally, natural regeneration and conservation actions such as planting are expected to be successful in the higher elevations within Monument subunit 2 and be sufficient to increase the future burn condition to low. Under Scenario 2, given worsening climate conditions and implementation of conservation measures, Monument subunits 2 and 3 are expected to be in very low overall condition.

Monument subunits 5 and 6

Monument subunit 5 is predicted to decrease from moderate to low and 6 is predicted to remain in very low condition for recruitment. Implementation of systematic surveys over the next 100 years is unlikely to yield multiple detections in Monument subunits 5 and 6 because wildfires have severely impacted much of the forested habitat (Figure 5.2). Although Monument subunit 5 is currently in moderate condition, the underlying habitat of the salamander locations suggest one location may decline in condition (see section 6.2.1 Resiliency Factor: Future Recruitment, above), resulting in a future recruitment condition of low. Additionally, Monument subunits 5 and 6 are comprised primarily of less favorable habitat (98% and 91%, respectively) in lower elevations, which is less likely to support salamanders under worsening climatic conditions predicted in SSP2-4.5. The amount of favorable habitat compared to all potential habitat is expected to remain in very low (Monument subunit 5) and increase from very low to low (Monument subunit 6) condition under the SSP2-4.5 predicted changes in climate. Monument subunits 5 and 6 contain a gradient of low to high elevations, and the highest-elevation areas are predicted to be less impacted in terms of rising temperatures and increased aridity (Figure 6.1). Following past wildfire history in Monument subunit 5, there is almost no remaining favorable habitat (less than 10 acres [4 ha]), and it is reasonable to assume loss of all favorable habitat within Monument subunit 5. Within Monument subunit 6, the amount of favorable habitat is high enough to suggest that in high-elevation areas, natural regeneration and planting could be sufficient to increase the amount of favorable habitat to low condition. Burn condition is expected to decrease from low to very low Monument subunits 5 and 6. Forest and fuels management can reduce but not eliminate wildfire risk in remaining unburned forested habitats and manage future wildlife risk during forest regeneration processes. Therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Further, forest regeneration is a slow process (Stevens-Rumann and Morgan 2019, p. 11) and is needed to replace the impacted forested habitat before regenerated habitat is expected to support salamander persistence. Under Scenario 2, given worsening climate conditions and implementation of conservation measures, Monument subunits 5 and 6 are expected to be in very low overall.

Forest West Unit

Under Scenario 2, Forest West Unit is expected to remain similar, on average, to current conditions with regard to overall conditions; four subunits change in condition, resulting in six subunits in moderate and one in very low overall condition. Overall future condition is predicted to remain the same as current overall condition for Forest West subunits 4 and 7 (moderate) and 6 (very low; Table 6.5, Figure 6.5). Overall future condition in Forest West subunits 1 and 2 are expected to decrease from high (current) to moderate (future), and Forest West subunits 3 and 5 are expected to increase from low (current) to moderate (future; Table 6.5, Figure 6.5).

Forest West subunits 1, 2, 3, 4, 5, and 7

Forest West subunits 1, 2, 3, 4, 5, and 7 increase to high recruitment condition from implementation of systematic surveys over the next 100 years. These subunits have been largely unimpacted by wildfires and are expected to yield salamander locations due to retention of salamander habitat (approximately 2,000 – 6, 000 acres [809-2,428 ha] of moderately and favorable habitat). The amount of favorable habitat compared to all potential habitat is expected to decrease from high to moderate (Forest West subunits 1, 2, and 4), from low to very low (Forest West subunit 7) and remain in very low condition (Forest West subunits 3 and 5) under the SSP2-4.5 predicted changes in climate. The predicted declines in favorable habitat are driven by worsening climatic conditions, with temperature driving the increased drop in condition in Forest West subunit 2 (Figure 6.1). Although a decline of up to 5 percent in favorable habitat from current conditions is not ideal, 15-20 percent of potential habitat is still ranked as favorable habitat in Forest West subunits 1, 2, and 4, and conservation measures to protect habitat occupied by salamanders are expected to be successful. Because up to 10 percent of potential habitat is still ranked as favorable habitat (Forest West subunits 3, 5, and 7), conservation measures to protect habitat occupied by salamanders are necessary and expected to be successful. Burn condition is expected to decline from high condition to moderate condition for these six subunits. Forest and fuels management are expected to reduce but not eliminate wildfire risk; therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Under Scenario 2, given worsening climate conditions and implementation of conservation measures Forest West subunits 1, 2, 3, 4, 5, and 7 are expected to be in overall moderate condition.

Forest West subunit 6

Forest West subunit 6 is predicted to be in low condition for recruitment. Implementation of systematic surveys over the next 100 years is predicted to increase the condition from very low/unknown to low but is unlikely to yield sufficient detections to document more than one location due to past wildfires (Figure 5.2) and amount of potential habitat available (Table 4.5). The amount of favorable habitat compared to all potential habitat is expected to remain in very low condition under the SSP2-4.5 predicted changes in climate. There are currently approximately 200 acres (81 ha; 5.6%) of favorable habitat in Forest West subunit 6; therefore, because little potential habitat may still be ranked as favorable habitat, conservation measures to protect habitat occupied by salamanders are necessary and expected to be successful. Burn condition is expected to decline from low to very low condition. Forest and fuels management are expected to reduce but not eliminate wildfire risk, therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Further, forest regeneration is a slow process (Stevens-Rumann and Morgan 2019, p. 11) and is needed to replace the impacted forested habitat before regenerated habitat is expected to support salamander persistence. Under Scenario 2, given worsening climate conditions and implementation of conservation measures, Forest West subunit 6 is expected to be in overall very low condition.

Preserve Unit

Under Scenario 2, the Preserve Unit is expected to remain the same as current conditions with regard to overall conditions. Overall future condition is predicted to remain the same as current overall condition for Preserve subunits 1, 2, and 3 (moderate); and 4, 5, 6 and 7 (low; Table 6.5, Figure 6.5).

Preserve subunit 2

Preserve subunit 2 increases from very low to high recruitment condition from implementation of systematic surveys over the next 100 years. The amount of favorable habitat compared to all potential habitat is expected to decrease from high to moderate under the SSP2-4.5 predicted changes in climate. The predicted declines in favorable habitat are driven by worsening climatic conditions (Figure 6.1). Although a decline of up to 5 percent in favorable habitat from current conditions is not ideal, 15-20 percent of potential habitat is still ranked as favorable habitat, and conservation measures to protect habitat occupied by salamanders are expected to be successful. Burn condition is expected to decline from high to moderate condition. Forest and fuels management are expected to reduce but not eliminate wildfire risk, therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Under Scenario 2, given worsening climate conditions and implementation of conservation measures, Preserve subunit 2 is expected to be in overall moderate condition.

Preserve subunits 1 and 3

Preserve subunits 1 and 3 are predicted to be in moderate condition for recruitment. For Preserve subunit 1, the increase is from implementation of systematic surveys over the next 100 years. For Preserve subunit 3, documentation of new salamander locations combined with the underlying habitat for the two current locations within this subunit is sufficient to retain the predicted moderate recruitment condition. The amount of favorable habitat compared to all potential habitat is expected to decrease from moderate to low (Preserve subunit 1) and remain in low condition (Preserve subunit 3) under the SSP2-4.5 predicted changes in climate. Although a decline of up to 5 percent in favorable habitat from current conditions is not ideal, 10-15 percent of potential habitat is still ranked as favorable habitat, and conservation measures to protect habitat occupied by salamanders are expected to be successful. Burn condition is expected to decrease from high to moderate (Preserve subunit 1) and remain in high (Preserve subunit 3) condition. Forest and fuels management are expected to reduce but not eliminate wildfire risk; therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Further, forest regeneration is a slow process (Stevens-Rumann and Morgan 2019, p. 11) and is needed to replace the impacted forested habitat before regenerated habitat is expected to support salamander persistence. Additionally, natural regeneration and conservation actions such as planting are expected to be successful in the higher elevations within Preserve subunit 3 and be sufficient to increase the future burn condition to low. Under Scenario 2, given worsening climate conditions and implementation of conservation measures, Preserve subunits 1 and 3 are expected to be in overall moderate condition.

Preserve subunit 5

Preserve subunit 5 is predicted to increase to moderate condition for recruitment from implementation of systematic surveys over the next 100 years. The amount of favorable habitat compared to all potential habitat is expected to remain in very low condition under the SSP2-4.5 predicted changes in climate. There are currently less than 10 acres (4 ha) of favorable habitat, and it is reasonable to assume loss of all favorable habitat within Preserve subunit 5. Conservation measures to protect all habitat occupied by salamanders are necessary. Burn condition is expected to decline from high to moderate condition for Preserve subunit 5. Forest and fuels management are expected to reduce but not eliminate wildfire risk; therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Further, forest regeneration is a slow process (Stevens-Rumann and Morgan 2019, p. 11) and is needed to replace the impacted forested habitat before regenerated habitat is expected to support salamander persistence. Under Scenario 2, given worsening climate conditions and implementation of conservation measures, Preserve subunit 5 is expected to be in overall low condition.

Preserve subunits 4, 6 and 7

Preserve subunits 4, 6, and 7 all increase from very low to low recruitment condition from implementation of systematic surveys over the next 100 years. The amount of favorable habitat compared to all potential habitat is expected to remain in high (Preserve subunit 4), low (Preserve subunit 6), and very low condition (Preserve subunit 7) under the SSP2-4.5 predicted changes in climate. Although a decline of up to 5 percent in favorable habitat from current conditions is not ideal, 10-15 percent of potential habitat is still ranked as favorable habitat in Preserve subunit 6, and conservation measures to protect habitat occupied by salamanders are expected to be successful. For Preserve subunit 7, currently there are less than 200 acres (81 ha) of favorable habitat remaining and it is reasonable to assume loss of all favorable habitat in the future (Figure 6.1). Burn condition is expected to decline from low to very low (Preserve subunit 4), moderate to low (Preserve subunit 6), and high to moderate (Preserve subunit 7) condition. Forest and fuels management are expected to reduce but not eliminate wildfire risk; therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Further, forest regeneration is a slow process (Stevens-Rumann and Morgan 2019, p. 11) and is needed to replace the impacted forested habitat before regenerated habitat is expected to support salamander persistence. Under Scenario 2, given worsening climate conditions and implementation of conservation measures, Preserve subunits 4, 6, and 7 are expected to be in overall low condition.

Table 6.5. Potential future conditions for each Jemez Mountains salamander subunit under Scenario 2.

Unit:subunit	Future Recruitment	Future Favorable Habitat	Future Burn	Future Overall Condition
Forest North:1	High	Low	Moderate	Moderate
Forest North:2	Moderate	Low	Moderate	Moderate
Forest North:3	Low	Very Low	Moderate	Low
Forest North:4	High	Low	Moderate	Moderate
Forest North:5	Moderate	Low	Moderate	Moderate
Forest North:6	High	Low	Moderate	Moderate
Forest North:7	Moderate	Low	Moderate	Moderate
Laboratory:1	Moderate	Low	Very Low	Low
Laboratory:2	Moderate	Moderate	Very Low	Low
Laboratory:3	Low	Very Low	Moderate	Low
Laboratory:4	Low	Very Low	Very Low	Very Low
Laboratory:5	Low	Low	Very Low	Low
Laboratory:6	Low	Very Low	Very Low	Very Low
Monument:1	High	Moderate	Very Low	Moderate
Monument:2	Very Low/Unknown	Low	Low	Very Low
Monument:3	Very Low/Unknown	Very Low	Low	Very Low
Monument:4	Moderate	Low	Very Low	Low
Monument:5	Low	Very Low	Very Low	Very Low
Monument:6	Very Low/Unknown	Low	Very Low	Very Low
Monument:7	Moderate	Low	Low	Low
Forest West:1	High	Moderate	Moderate	Moderate
Forest West:2	High	Moderate	Moderate	Moderate
Forest West:3	High	Very Low	Moderate	Moderate
Forest West:4	High	Moderate	Moderate	Moderate
Forest West:5	High	Very Low	Moderate	Moderate
Forest West:6	Low	Very Low	Very Low	Very Low
Forest West:7	High	Very Low	Moderate	Moderate
Preserve:1	Moderate	Low	Moderate	Moderate
Preserve:2	High	Moderate	Moderate	Moderate
Preserve:3	Moderate	Low	High	Moderate
Preserve:4	Low	High	Very Low	Low
Preserve:5	Moderate	Very Low	Moderate	Low
Preserve:6	Low	Low	Low	Low
Preserve:7	Low	Very Low	Moderate	Low

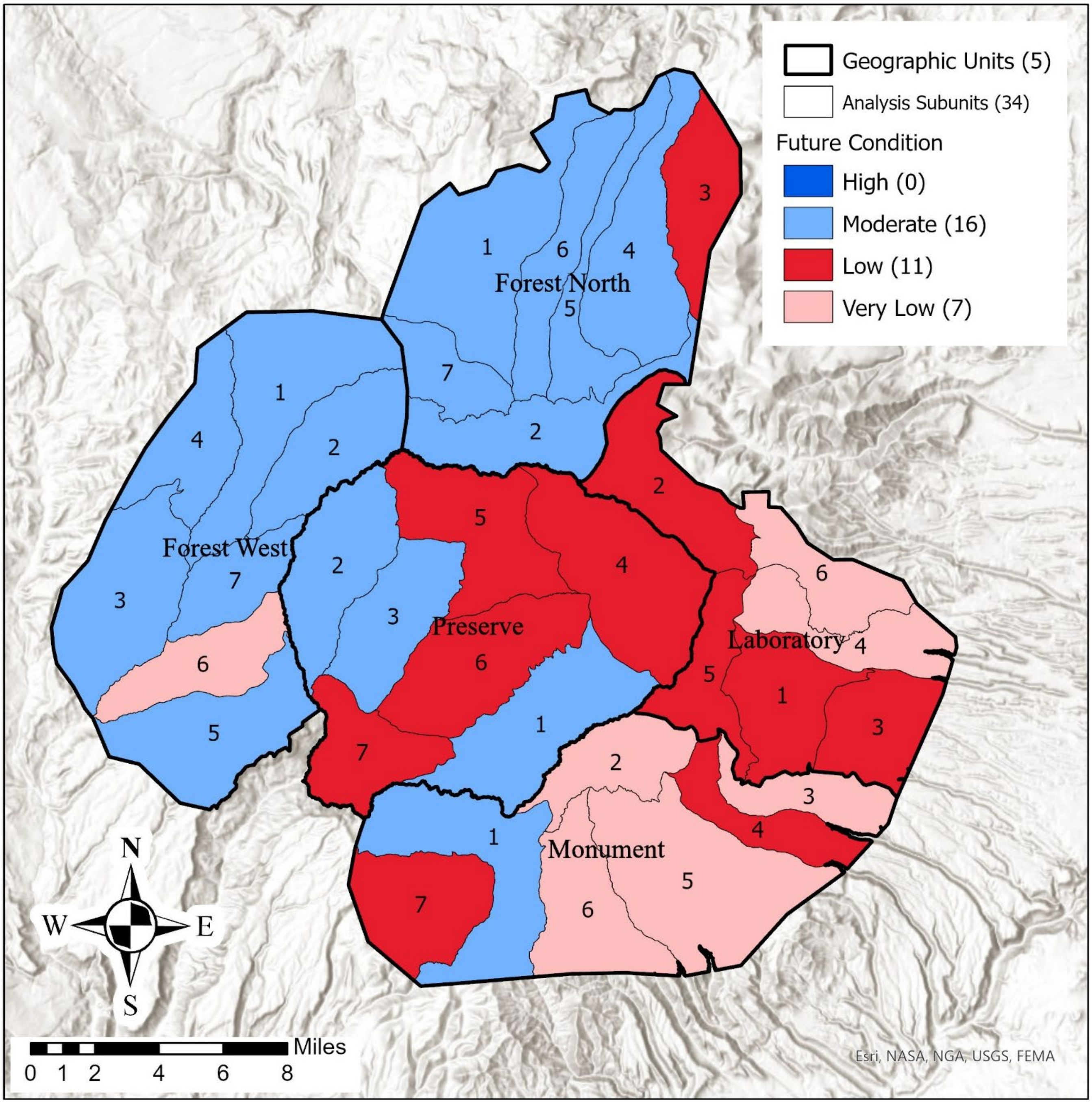

Figure 6.5. Projected future overall resiliency condition in 100 years under Scenario 2.

6.4.3 *Scenario 3*: Greater Stressor Increase and Increase in Conservation Actions

As stated previously in section 6.2.2 Resiliency Factors: Future Habitat and Burn, calculations for Scenario 3 (SSP5-8.5 for 60-100 years) IMD (moisture deficit), SMTI (increased temperature), ACWE (change in show water equivalent), and PCWRD (wetting rain days) for all Jemez Mountains salamander subunits were determined and used by the salamander SSA team to help assign the future favorable habitat and future burn conditions (Figure 6.2, Figure 6.3, Table 6.3)**Figure 6.3**. This information, along with the modeled future recruitment (from section 6.2.1 Resiliency Factor: Future Recruitment), was used to determine the overall future condition for each subunit. Future conditions, organized by Unit, for Scenario 3 are discussed below. Current conditions for each unit referenced below are found in Table 4.7.

Forest North Unit

Under Scenario 3, the Forest North Unit is expected to change slightly compared to current conditions with regard to overall conditions; four subunits change in condition, resulting in five subunits in low and two in moderate overall condition. Overall future condition is predicted to remain the same as current overall condition for Forest North subunits 2, 3 (low), and 7 (moderate; Table 6.6, Figure 6.6). Overall future condition in Forest North subunit 1 is expected to increase from low (current) to moderate (future), and Forest North subunits 4, 5, and 6 are expected to decline from moderate (current) to low condition (future; Table 6.6, Figure 6.6).

Forest North subunits 1 and 7

Currently Forest North subunits 1, and 7 are in very low/unknown condition for recruitment due to lack of historical survey efforts. Implementation of systematic surveys over the next 100 years is predicted to increase future recruitment condition to moderate (Forest North subunit 1) and low condition (Forest North subunit 7). The amount of favorable habitat compared to all potential habitat is expected to remain low (Forest North subunit 1) or decrease from high (Forest North subunit 7) to moderate condition under the SSP5-8.5 predicted changes in climate. Although a decline in favorable habitat of 5 percent from current conditions (Forest North subunit 7) is not ideal, 10-20 percent of potential habitat is still ranked as favorable habitat, and conservation measures to protect habitat occupied by salamanders are expected to be successful. Conservation measures implemented in Forest North subunit 1 are expected to be sufficient to limit future favorable habitat loss to less than 5 percent but not sufficient to increase future favorable habitat by 1 percent. Burn condition is expected to decline from high condition to moderate condition for Forest North subunits 1 and 7. Forest and fuels management are expected to reduce but not eliminate wildfire risk; therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Under Scenario 3, given worsening climate conditions and implementation of conservation measures, Forest North subunits 1and 7 are expected to be in overall moderate condition.

Forest North subunits 2 and 3

Currently Forest North subunits 2 and 3 are in very low/unknown condition for recruitment due to lack of historical survey efforts. Implementation of systematic surveys over the next 100 years is predicted to increase future recruitment condition to low in Forest North subunit 2. Future recruitment is predicted to remain the same (very low/unknown condition) for Forest North subunit 3. Implementation of systematic surveys over the next 100 years is unlikely to yield multiple detections sufficient to increase future recruitment condition in Forest North subunit 3 because currently over 80 percent of potential habitat is less-favorable habitat which is expected to be impacted by future environmental changes, such that it may lack characteristics in the future needed to support salamander persistence. The amount of favorable habitat compared to all potential habitat is expected to decrease from low to very low condition (Forest North subunit 2) and remain in very low condition (Forest North subunit 3) under the SSP5-8.5 predicted changes in climate. Although declines in favorable habitat of 5 percent from current conditions is concerning in Forest North 2, up to 10 percent of potential habitat is still ranked as favorable habitat; thus, conservation measures to protect habitat occupied by salamanders are necessary and expected to be successful. In Forest North subunit 3, 4.6 percent (less than 200 acres [81 ha]) of potential habitat is ranked as favorable habitat (Table 4.5); therefore, given the 5 percent loss of favorable habitat expected, it is reasonable to assume loss of all favorable habitat within Forest North subunit 3. Burn condition is expected to decline from high condition to moderate condition for both subunits. Forest and fuels management are expected to reduce but not eliminate wildfire risk; therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Under Scenario 3, given worsening climate conditions and implementation of conservation measures, Forest North subunits 2 and 3 are expected to be in overall low condition.

Forest North subunits 4, 5, and 6

Currently Forest North subunits 4, 5, and 6 are in very low/unknown condition for recruitment due to lack of historical survey efforts. Implementation of systematic surveys over the next 100 years is predicted to increase future recruitment condition to low in all subunits. The amount of favorable habitat compared to all potential habitat is expected to decrease from moderate to low condition for these three subunits under the SSP5-8.5 predicted changes in climate. Although declines in favorable habitat of 5 percent from current conditions is concerning, 10-15 percent of potential habitat is still ranked as favorable habitat, and conservation measures to protect habitat occupied by salamanders are expected to be successful. Burn condition is expected to decline from high condition to moderate condition for Forest North subunits 4, 5, and 6. Forest and fuels management are expected to reduce but not eliminate wildfire risk; therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Under Scenario 3, given worsening climate conditions and implementation of conservation measures, Forest North subunits 4, 5, and 6 are expected to be in overall low condition.

Laboratory Unit

Under Scenario 3, the Laboratory Unit is expected to decline compared to current conditions with regard to overall conditions; three subunits remain in low condition and three subunits decline from low to very low overall condition. Overall future condition is predicted to remain the same as current overall condition for Laboratory subunits 2, 3, and 4 (all low; Table 6.6, Figure 6.6). Overall future condition for Laboratory subunits 1, 5, and 6 is expected to decline from low (current) to very low (future; Table 6.6, Figure 6.6).

Laboratory subunit 3

Currently Laboratory subunit 3 is in low condition for recruitment due to inconsistent historical and recent survey efforts within the Laboratory Unit. Future recruitment is predicted to remain the same in Laboratory subunit 3. Implementation of systematic surveys over the next 100 years is unlikely to yield multiple detections in Laboratory subunit 3 because wildfires have severely impacted much of the forested habitat (Figure 5.2). Forest regeneration is a slow process (Stevens-Rumann and Morgan 2019,

p. 11) and is needed to replace the impacted forested habitat before regenerated habitat is expected to support salamander persistence. Laboratory subunit 3 is comprised primarily of less favorable habitat in lower elevations, which is predicted to be more impacted in terms of rising temperatures, decreased precipitation, and increased aridity (Figure 6.2). Such changes, predicted in SSP5-8.5, are expected to modify habitat conditions such that less favorable habitat in lower elevations areas is unlikely to support salamanders in the future. The amount of favorable habitat compared to all potential habitat is expected to remain in very low condition under the SSP5-8.5 predicted changes in climate. Since this subunit contains less than 10 acres (4 ha) of favorable habitat, it is reasonable to assume loss of all favorable habitat within Laboratory subunit 3. Conservation measures to protect habitat occupied by salamanders are necessary and expected to be successful. Burn condition is expected to decline from high to low condition for Laboratory subunit 3. Forest and fuels management can reduce but not eliminate wildfire risk in remaining unburned forested habitats and manage future wildlife risk during forest regeneration processes. Therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Under Scenario 3, given worsening climate conditions and implementation of conservation measures, Laboratory subunit 3 is expected to remain in overall low condition.

Laboratory subunits 1, 2, 4, 5, and 6

Currently Laboratory subunits 1 and 4 are in moderate condition and Laboratory subunits 2, 5, and 6 are in low condition for recruitment. Future recruitment is predicted to decline to low (Laboratory subunits 1 and 4) and very low condition (Laboratory subunits 2, 5, and 6). Implementation of systematic surveys over the next 100 years is unlikely to yield additional detections because wildfires have severely impacted much of the forested habitat (Figure 5.2). Forest regeneration is a slow process (Stevens-Rumann and Morgan 2019, p. 11) and is needed to replace the impacted forested habitat before regenerated habitat is expected to support salamander persistence. Although Laboratory subunits 1 and 4 are currently in moderate condition and Laboratory subunits 2, 5, and 6 are currently in low condition, the underlying habitat of the salamander locations in these subunits suggest the locations may decline in condition or be lost (see section 6.2.1 Resiliency Factor: Future Recruitment, above), resulting in a future recruitment condition of low and very low, respectively. The amount of favorable habitat compared to all potential habitat is expected to remain in low (Laboratory subunit 2) and very low condition (Laboratory subunits 1, 4, 5, and 6) under the SSP5-8.5 predicted changes in climate. Laboratory subunit 2 is comprised of the highest-elevation areas within the Laboratory Unit, which is predicted to be less impacted in terms of rising temperatures and increased aridity (Figure 6.2) than adjacent subunits. Therefore, we expect it to maintain current levels of favorable habitat. Laboratory subunits 1, 4, 5 and 6 are comprised primarily of less favorable habitat (70 to 90%) and contain, in part, low-elevation areas which are predicted to be more impacted in terms of rising temperatures, decreasing precipitation, and increased aridity (Figure 6.2). Following past wildfire history, they each contain less than 200 acres (81 ha) of favorable habitat, and it is reasonable to assume loss of all favorable habitat within Laboratory subunits 1, 4, 5, and 6. Conservation measures to protect habitat occupied by salamanders are necessary and expected to be successful. Burn condition is expected to decline from low to very low condition for Laboratory subunits 1, 2, 4, 5, and 6. Forest and fuels management can reduce but not eliminate wildfire risk in remaining unburned forested habitats and manage future wildlife risk during forest regeneration processes. Therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Under Scenario 3, given worsening climate conditions and implementation of conservation measures Laboratory subunit 1, 2, 4, 5, and 6 are expected to be in overall very low condition.

Monument Unit

Under Scenario 3, the Monument Unit is expected to decline slightly compared to current conditions with regard to overall conditions; three subunits decline in condition, resulting in two subunits in low and five in very low overall condition. Overall future condition is predicted to remain the same as current overall condition for Monument subunits 2, 4, 6, and 7 (low for 4 and 7, very low for 2 and 6; Table 6.6, Figure 6.6). Overall future condition in Laboratory subunits 1, 3, and 5 are expected to decline from low (current) to very low (future; Table 6.6, Figure 6.6).

Monument subunits 4 and 7

Under Scenario 3, future recruitment is predicted to be in moderate (Monument subunit 4) and low condition (Monument subunit 7). Monument subunit 4 is comprised largely of lower-elevation areas with less favorable habitat, suggesting lower levels of resiliency to worsening climatic conditions in much of this subunit. However, the underlying habitat of the current salamander locations suggest we will retain those locations, and they will remain in moderate condition (see section 6.2.1 Resiliency Factor: Future Recruitment, above). The increase in future recruitment from very low/unknown to low condition in Monument subunit 7 is a result of the implementation of systematic surveys over the next 100 years. This subunit has the second most favorable and potential habitat (within the Monument Unit, Table 4.5) at higher elevations which provides some level of resiliency to worsening climatic conditions. The amount of favorable habitat compared to all potential habitat is expected to remain in very low condition (Monument subunit 4) and decrease from low to very low condition (Monument subunit 7) under the SSP5-8.5 predicted changes in climate. Monument subunit 7 contains over 2,000 acres (809 ha) of favorable and moderately favorable habitat in higher-elevation areas, and although they are expected to be less impacted by rising aridity and temperatures than less favorable habitat in lower elevation areas, the conditions are thought sufficient to expect a decline in the condition of future favorable habitat. Monument subunit 4 is within a transition of higher- to lower elevation areas and will be differentially impacted by rising temperatures and increased aridity (Figure 6.2) along its elevational gradient. Following past wildfire history, fewer than 50 acres (20 ha) of favorable habitat currently remain, and it is reasonable to assume loss of all favorable habitat within Monument subunit 4. Burn condition is expected to decline from moderate to low (Monument subunit 7) and from low to very low condition (Monument subunit 4). Forest and fuels management can reduce but not eliminate wildfire risk in remaining unburned forested habitats and manage future wildlife risk during forest regeneration processes. Therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Further, forest regeneration is a slow process (Stevens-Rumann and Morgan 2019, p. 11) and is needed to replace the impacted forested habitat before regenerated habitat is expected to support salamander persistence. Under Scenario 3, given worsening climate conditions and implementation of conservation measures, Monument subunits 4 and 7 are expected to be in overall low condition.

Monument subunits 1 and 5

Monument subunit 1 is predicted to remain in low condition and Monument subunit 5 is predicted to decrease from moderate to low condition for recruitment. Implementation of systematic surveys over the next 100 years is unlikely to yield multiple detections in these subunits because wildfires have severely impacted much of the forested habitat (Figure 5.2). Forest regeneration is a slow process (Stevens-Rumann and Morgan 2019, p. 11) and is needed to replace the impacted forested habitat before regenerated habitat is expected to support salamander persistence. Although Monument subunit 5 is currently in moderate condition and Monument subunit 1 is currently in low condition, the underlying habitat of the salamander locations in these subunits suggest the locations may decline in condition (see section 6.2.1 Resiliency Factor: Future Recruitment, above), resulting in future recruitment conditions of low. The amount of favorable habitat compared to all potential habitat is expected to decrease from low to very low (Monument subunit 1) and remain in very low condition (Monument subunit 5) under the SSP5-8.5 predicted changes in climate. Monument subunit 1 contains over 2,000 acres (809 ha) of favorable and moderately favorable habitat in higher-elevation areas, and although they are expected to be less impacted by rising aridity than less favorable habitat in lower elevation areas, the conditions are thought sufficient to expect a decline in the condition of future favorable habitat. Monument subunit 5 is within a transition of higher- to lower-elevation areas and will be differentially impacted by rising temperatures and increased aridity (Figure 6.2) along its elevational gradient. Following past wildfire history, only 10 acres (4 ha) of favorable habitat currently remain, and it is reasonable to assume loss of all favorable habitat within Monument subunit 5. Conservation measures to protect habitat occupied by salamanders are necessary and expected to be successful. Burn condition is expected to decline from low to very low condition for both subunits. Forest and fuels management can reduce but not eliminate wildfire risk in remaining unburned forested habitats and manage future wildlife risk during forest regeneration processes. Therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Under Scenario 3, given worsening climate conditions and implementation of conservation measures, Monument subunits 1 and 5 are expected to be in overall very low condition.

Monument subunits 2, 3, and 6

Monument subunits 2, 3, and 6 are predicted to remain in very low condition for recruitment. Implementation of systematic surveys over the next 100 years is unlikely to yield multiple detections in these subunits because wildfires have severely impacted much of the forested habitat (Figure 5.2). Additionally, Monument subunit 3 is comprised primarily of less favorable habitat in lower elevations, which is unlikely to support salamanders under worsening climatic conditions predicted in SSP5-8.5. The amount of favorable habitat compared to all potential habitat is expected to decrease from low to very low (Monument subunit 2) and remain in very low (Monument subunits 3 and 6) condition under the SSP5-8.5 predicted changes in climate. Although Monument subunit 2 is in higher elevations relative to adjacent subunits in the Monument Unit, the current amount of favorable habitat (less than 200 acres [81 ha]) is low enough to suggest that worsening climatic conditions could result in the loss of all favorable habitat. Monument subunits 3 and 6 are within a transition of higher- to lower-elevation areas and will be differentially impacted by rising temperatures and increased aridity (Figure 6.2) along their elevational gradients. Following past wildfire history, they each contain fewer than 100 acres (40 ha) of favorable habitat, and it is reasonable to assume loss of all favorable habitat within Monument subunits 3 and 6. Additionally, in Monument subunit 3 there is currently little remaining potential habitat (~1000 acres [405 ha]), most of which is less favorable habitat and predicted to be impacted in terms of rising temperatures and increased aridity (Figure 6.2). Burn condition is expected to increase from very low to low (Monument subunit 2), decrease from low to very low (Monument subunit 6), and decrease from moderate to low (Monument subunit 3) condition. Forest and fuels management can reduce but not eliminate wildfire risk in remaining unburned forested habitats and manage future wildlife risk during forest regeneration processes. Therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Further, forest regeneration is a slow process (Stevens-Rumann and Morgan 2019, p. 11) and is needed to replace the impacted forested habitat before regenerated habitat is expected to support salamander persistence. Additionally, natural regeneration and conservation actions such as planting are expected to be successful in the higher elevations within Monument subunit 2 and be sufficient to increase the future burn condition to low. Under Scenario 3, given worsening climate conditions and implementation of conservation measures, Monument subunits 2, 3, and 6 are expected to be in overall low condition.

Forest West Unit

Under Scenario 3, Forest West Unit is expected to decrease compared to current conditions with regard to overall conditions; three subunits decline in condition, resulting in three subunits in moderate, three in low, and one in very low overall condition. Overall future condition is predicted to remain the same as current overall condition for Forest West subunits 4 (moderate), 3 and 5 (low), and 6 very low (Table 6.6, Figure 6.6. Overall future condition in Forest West subunits 1 and 2 are expected to decline from high (current) to moderate (future), and from moderate (current) to low (future; Table 6.6, Figure 6.6) for Forest West subunits 7.

Forest West subunits 1, 2, and 4

Forest West subunit 1 is predicted to remain in moderate condition, and Forest West subunit 4 is predicted to increase from very low to low recruitment condition, from implementation of systematic surveys over the next 100 years. Although Forest west subunit 2 is currently in high condition, the underlying habitat of the salamander locations in this subunit suggests the locations may decline to moderate condition (see section 6.2.1 Resiliency Factor: Future Recruitment, above). The amount of favorable habitat compared to all potential habitat is expected to decrease from high to moderate condition for these three subunits under the SSP5-8.5 predicted changes in climate. Although a decline of up to 5 percent in favorable habitat from current conditions is not ideal, 15-20 percent of potential habitat is still ranked as favorable habitat in Forest West subunits 1, 2, and 4, and conservation measures to protect habitat occupied by salamanders are expected to be successful. Burn condition is expected to decline from high to moderate condition for these three subunits. Forest and fuels management are expected to reduce but not eliminate wildfire risk, therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Under Scenario 3, given worsening climate conditions and implementation of conservation measures, Forest West subunits 1, 2, and 4 are expected to be in overall moderate condition.

Forest West subunits 3, 5, and 7

Forest West subunit 7 is predicted to decrease to moderate condition. Although Forest west subunit 7 is currently in high condition, the underlying habitat of the salamander locations in this subunit suggests the locations may decline to moderate condition (see section 6.2.1 Resiliency Factor: Future Recruitment, above). Forest West subunits 3 and 5 are predicted to increase to moderate and low recruitment condition, respectively, from implementation of systematic surveys over the next 100 years. The amount of favorable habitat compared to all potential habitat is expected to decrease from low to very low (Forest West subunit 7) and remain in very low condition (Forest West subunits 3 and 5) under the SSP5-8.5 predicted changes in climate. Because up to 10 percent of potential habitat is still ranked as favorable habitat (Forest West subunits 3, 5 and 7), conservation measures to protect habitat occupied by salamanders are necessary and expected to be successful. Burn condition is expected to decline from high condition to moderate condition for these three subunits. Forest and fuels management are expected to reduce but not eliminate wildfire risk; therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Under Scenario 3, given worsening climate conditions and implementation of conservation measures, Forest West subunits 3, 5, and 7 are expected to be in overall low condition.

Forest West subunit 6

Forest West subunit 6 is predicted to remain in very low/unknown condition for recruitment. Implementation of systematic surveys over the next 100 years is unlikely to yield multiple detections, since wildfires have severely impacted 21 percent of the forested habitat (Figure 5.2) and much of the remaining potential habitat is less favorable habitat (77 %). There are currently approximately 200 acres (81 ha) of favorable habitat in Forest West subunit 6, and less favorable habitat may be incapable of supporting salamanders under Scenario 3. Forest regeneration is a slow process (Stevens-Rumann and Morgan 2019, p. 11) and is needed to replace the impacted forested habitat before regenerated habitat is expected to support salamander persistence. The amount of favorable habitat compared to all potential habitat is expected to remain in very low condition under the SSP5-8.5 predicted changes in climate. Burn condition is expected to decline from low to very low condition. Forest and fuels management are expected to reduce but not eliminate wildfire risk; therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Under Scenario 3, given worsening climate conditions and implementation of conservation measures, Forest West subunit 6 is expected to be in overall very low condition.

Preserve Unit

Under Scenario 3, the Preserve Unit is expected to remain in similar conditions to current conditions with regard to overall conditions. Overall future condition is predicted to remain the same as current overall condition for Preserve subunits 1 and 2 (moderate) and 4, 5, 6 and 7 (low; Table 6.6, Figure 6.6). Overall future condition in Preserve subunit 3 is expected to decline from moderate to low condition (Table 6.6, Figure 6.6).

Preserve subunits 1 and 2

Preserve subunit 1 is predicted to remain in low condition and Preserve subunit 2 increases from very low to low recruitment condition. Implementation of systematic surveys over the next 100 years is not likely to yield multiple new detections in these subunits. The amount of favorable habitat compared to all potential habitat is expected to decrease from high to moderate (Preserve subunit 2) and from moderate to low (Preserve subunit 1) condition under the SSP5-8.5 predicted changes in climate. Although a decline of up to 5 percent in favorable habitat from current conditions is not ideal, 10-20 percent of potential habitat is still ranked as favorable habitat in Preserve subunits 1 and 2, and conservation measures to protect habitat occupied by salamanders are expected to be successful. Burn condition is expected to decrease from high to moderate condition in both subunits. Forest and fuels management is expected to reduce but not eliminate wildfire risk; therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Under Scenario 3, given worsening climate conditions and implementation of conservation measures, Preserve subunits 1 and 2 are expected to be in overall moderate condition.

Preserve subunits 3, 5, and 7

Preserve subunits 3, 5, and 7 are predicted to be in low condition for recruitment. Implementation of systematic surveys over the next 100 years is not likely to yield multiple locations in Preserve subunits 5 and 7 but is sufficient to increase future recruitment condition. For Preserve subunit 3, multiple locations are not expected to be detected during implementation of systematic surveys, and underlying habitat for the two current locations within this subunit is not sufficient to retain the current recruitment condition. The amount of favorable habitat compared to all potential habitat is expected to decrease from low to very low (Preserve subunit 3) or remain in very low (Preserve subunits 5 and 7) condition under the SSP5-8.5 predicted changes in climate. For Preserve subunits 5 and 7, currently there are less than 200 acres (81 ha) of favorable habitat remaining, and it is reasonable to assume loss of all favorable habitat in the future (Figure 6.2). Because up to 10 percent of potential habitat is still ranked as favorable habitat, conservation measures to protect habitat occupied by salamanders are necessary and expected to be successful. Burn condition is expected to decrease from high to moderate condition for these three subunits. Forest and fuels management is expected to reduce but not eliminate wildfire risk; therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Under Scenario 3, given worsening climate conditions and implementation of conservation measures, Preserve subunits 3, 5, and 7 are expected to be in overall low condition.

Preserve subunits 4 and 6

Preserve subunits 4 and 6 increase from very low to low recruitment condition from implementation of systematic surveys over the next 100 years. The amount of favorable habitat compared to all potential habitat is expected to remain in low (Preserve subunit 6) and decrease from high to moderate condition (Preserve subunit 4) under the SSP5-8.5 predicted changes in climate. Although a decline of up to 5 percent in favorable habitat from current conditions in Preserve subunit 4 is not ideal, 10-20 percent of potential habitat is still ranked as favorable habitat in these subunits, and conservation measures to protect habitat occupied by salamanders are expected to be successful. Burn condition is expected to decline from low to very low (Preserve subunit 4) and moderate to low (Preserve subunit 6) condition. Forest and fuels management are expected to reduce but not eliminate wildfire risk; therefore, we expect wildfires to occur but not at the scale seen over the past two decades. Further, forest regeneration is a slow process (Stevens-Rumann and Morgan 2019, p. 11) and is needed to replace the impacted forested habitat before regenerated habitat is expected to support salamander persistence. Under Scenario 3, given worsening climate conditions and implementation of conservation measures, Preserve subunits 4 and 6 are expected to be in overall low condition.

Table 6.6. Potential future conditions for each Jemez Mountains salamander subunit under Scenario 3.

Unit:subunit	Future Recruitment	Future Favorable Habitat	Future Burn	Future Overall Condition
Forest North:1	Moderate	Low	Moderate	Moderate
Forest North:2	Low	Very Low	Moderate	Low
Forest North:3	Very Low/Unknown	Very Low	Moderate	Low
Forest North:4	Low	Low	Moderate	Low
Forest North:5	Low	Low	Moderate	Low
Forest North:6	Low	Low	Moderate	Low
Forest North:7	Low	Moderate	Moderate	Moderate
Laboratory:1	Low	Very Low	Very Low	Very Low
Laboratory:2	Very Low/Unknown	Low	Very Low	Very Low
Laboratory:3	Low	Very Low	Low	Low
Laboratory:4	Low	Very Low	Very Low	Very Low
Laboratory:5	Very Low/Unknown	Very Low	Very Low	Very Low
Laboratory:6	Very Low/Unknown	Very Low	Very Low	Very Low
Monument:1	Low	Very Low	Very Low	Very Low
Monument:2	Very Low/Unknown	Very Low	Low	Very Low
Monument:3	Very Low/Unknown	Very Low	Low	Very Low
Monument:4	Moderate	Very Low	Very Low	Low
Monument:5	Low	Very Low	Very Low	Very Low
Monument:6	Very Low/Unknown	Very Low	Very Low	Very Low
Monument:7	Low	Very Low	Low	Low
Forest West:1	Moderate	Moderate	Moderate	Moderate
Forest West:2	Moderate	Moderate	Moderate	Moderate
Forest West:3	Moderate	Very Low	Moderate	Low
Forest West:4	Low	Moderate	Moderate	Moderate
Forest West:5	Low	Very Low	Moderate	Low
Forest West:6	Very Low/Unknown	Very Low	Very Low	Very Low
Forest West:7	Moderate	Very Low	Moderate	Low
Preserve:1	Low	Low	Moderate	Moderate
Preserve:2	Low	Moderate	Moderate	Moderate
Preserve:3	Low	Very Low	Moderate	Low
Preserve:4	Low	Moderate	Very Low	Low
Preserve:5	Low	Very Low	Moderate	Low
Preserve:6	Low	Low	Low	Low
Preserve:7	Low	Very Low	Moderate	Low

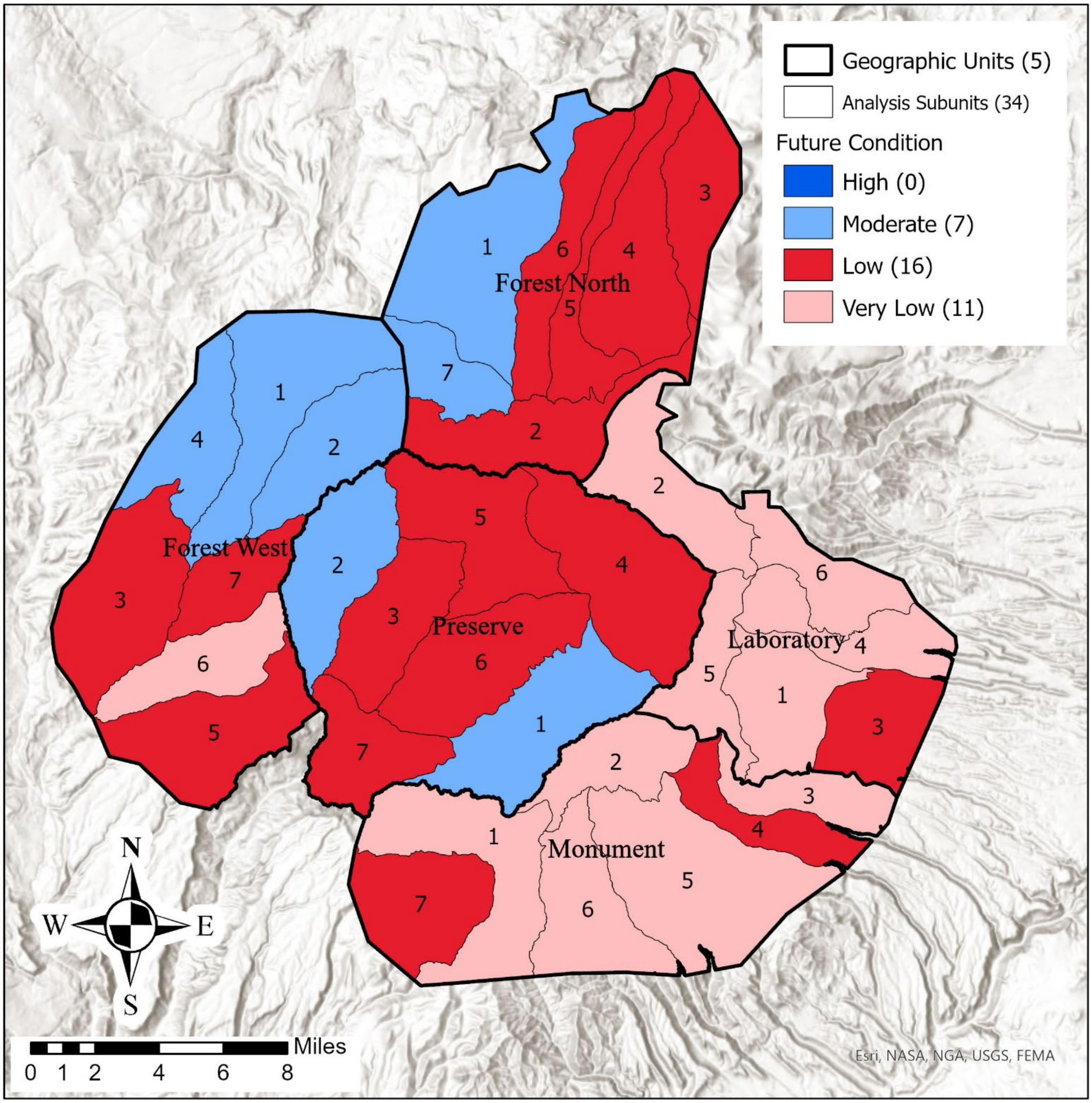

Figure 6.6. Projected future overall resiliency condition in 100 years under Scenario 3.

6.4.4 Future Resiliency Summary

We assessed the potential future resiliency of Jemez Mountains salamander subunits through three different but plausible future scenarios. For each scenario, we varied the levels of stressors and conservation efforts going forward based on the current stressors affecting each Unit, assumptions of future stressors and effects of those stressors, and potential levels of protection and management efforts going forward. Our assessments of these future scenarios, described in detail above, are summarized here and compared to the current condition of each population (Table 6.7).

Table 6.7. Jemez Mountains salamander overall resiliency conditions currently and under Future Scenarios 1 through 3 by subunit.

Unit:subunit	Current Condition	Future Scenario 1	Future Scenario 2	Future Scenario 3
Forest North:1	Low	Moderate	Moderate	Moderate
Forest North:2	Low	Moderate	Moderate	Low
Forest North:3	Low	Low	Low	Low
Forest North:4	Moderate	Moderate	Moderate	Low
Forest North:5	Moderate	Moderate	Moderate	Low
Forest North:6	Moderate	Moderate	Moderate	Low
Forest North:7	Moderate	Moderate	Moderate	Moderate
Laboratory:1	Low	Low	Low	Very Low
Laboratory:2	Low	Low	Low	Very Low
Laboratory:3	Low	Low	Low	Low
Laboratory:4	Low	Low	Very Low	Very Low
Laboratory:5	Low	Very Low	Low	Very Low
Laboratory:6	Low	Low	Very Low	Very Low
Monument:1	Low	Low	Moderate	Very Low
Monument:2	Very Low/Unknown	Very Low	Very Low	Very Low
Monument:3	Low	Low	Very Low	Very Low
Monument:4	Low	Low	Low	Low
Monument:5	Low	Low	Very Low	Very Low
Monument:6	Very Low/Unknown	Very Low	Very Low	Very Low
Monument:7	Low	Low	Low	Low
Forest West:1	High	High	Moderate	Moderate
Forest West:2	High	High	Moderate	Moderate
Forest West:3	Low	Moderate	Moderate	Low
Forest West:4	Moderate	Moderate	Moderate	Moderate
Forest West:5	Low	Low	Moderate	Low
Forest West:6	Very Low/Unknown	Very Low	Very Low	Very Low
Forest West:7	Moderate	Moderate	Moderate	Low
Preserve:1	Moderate	Moderate	Moderate	Moderate
Preserve:2	Moderate	Moderate	Moderate	Moderate
Preserve:3	Moderate	Moderate	Moderate	Low
Preserve:4	Low	Low	Low	Low
Preserve:5	Low	Low	Low	Low
Preserve:6	Low	Low	Low	Low
Preserve:7	Low	Low	Low	Low

6.5 Future Redundancy

Redundancy reduces the risk that a large portion of the species' range will be negatively affected by a catastrophic natural or anthropogenic event. Species that occur as multiple populations distributed across larger ranges are likely less susceptible to extinction than are species that occur as a single population within a smaller range. As we have described in this SSA, the Jemez Mountains salamander is a narrow endemic with a naturally limited range. The salamander's current distribution is estimated to occur within five Units that range in size from approximately 42,000 to 68,000 acres (16,997 to 27,519 ha; see section 3.2 Current Distribution and Salamander Detections for more information), and these Units are found only within the Jemez Mountains in northern New Mexico. Jemez Mountains salamanders require multiple resilient subunits (SSA surrogate for populations) distributed across the breadth of the species' range (Units) to provide for redundancy.

In this SSA, we assessed resiliency of subunits based on recruitment, favorable habitat, and burn. We determined that of 34 subunits, 2 subunits are currently in high condition overall and 9 subunits are in moderate condition overall (Figure 4.2). Currently, 9 of 34 subunits are in high (3) or moderate (6) recruitment condition, indicating Jemez Mountains salamander persistence in those 9 subunits over time and within the last 10 to 15 years (Figure 4.3), while 25 of 34 subunits are in low or very low/unknown recruitment condition. With an increase in survey effort, our assumptions and associated modeling suggest that we will likely detect salamanders in areas of salamander habitat across the species' range over time. These detections increase future recruitment condition in 14 to 20 subunits under all three future scenarios; however, 1 to 9 subunits are expected to decline in recruitment condition in the future.

In the near future, projected in Scenario 1 (15 years), 3 subunits increase and 1 subunit decreases in overall resiliency condition (Table 6.4). Although these changes in overall resiliency are slightly positive, redundancy is not substantially different from current conditions. Subunits with high (2) and moderate (12) resiliency are mostly lumped together across 3 adjacent Units, which places them at risk of impacts from a large-scale wildfire. Further, 7 of 12 subunits in moderate resiliency condition are projected to have low recruitment condition. Therefore, in 15 years, under Scenario 1, we consider future redundancy to remain poor for the Jemez Mountains salamander.

As we look further into the future under Scenarios 2 and 3 (100 years) we predict that no subunit will be in high overall resiliency condition, and overall resiliency condition will decrease in 7 subunits (under Scenario 2) and decrease for 15 subunits (under Scenario 3). The increase in resiliency condition in 4 subunits (under Scenario 2) and 1 subunit (under Scenario3) is not sufficient to offset the number of subunits expected to decline in future resiliency condition. Under Scenarios 2 and 3, 16 of 34 subunits (47%) and 7 of 34 subunits (21%) are in moderate resiliency condition, respectively (Table 6.6). Although almost half of the subunits under Scenario 2 are in moderate overall resiliency, this is largely driven by the model assumptions associated with increases in salamander detections from increased survey effort (see section 6.2 Conservation Actions, Future Resiliency Factors, and Assumptions, above). Future projections predict that salamanders are not detected in 14 of 18 (Scenario 2) and 24 of 28 (Scenario 3) subunits with low or very low future resiliency for over 15 years, suggesting salamanders may no longer persist in those subunits. Additionally, subunits with moderate future resiliency under Scenarios 2 and 3 are mostly lumped together in adjacent Units (Figures 6.2 and 6.3) comprised of contiguous mature forests that are currently largely unimpacted by wildfire. A single large-scale wildfire, such as the 2011 Las Conchas Fire, could have catastrophic impacts under these scenarios. Under Scenarios 2 and 3, no subunits are in high condition, and all moderate-condition subunits are largely grouped together spatially and vulnerable to catastrophic events. Therefore, future redundancy is considered relatively poor under these future scenarios.

6.6 Future Representation

Representation in the form of genetic or ecological diversity is important in maintaining the ability of Jemez Mountains salamanders to adapt to future environmental change. However, since the Jemez Mountains salamander is a narrow endemic that is found only in ponderosa pine-dominated, mixed-conifer, and subalpine spruce-fir forests in the Jemez Mountains in New Mexico, genetic and ecological diversity was likely historically and is still currently limited. Climate models project decreases in moistures, snow fall, and wetting rain days (May – September) and increases in temperatures, which will alter the forested habitat within the Jemez Mountains. These changes are predicted to lead to decreases in available Jemez Mountains salamander habitat and increased impacts from wildfire on this habitat. Implementation of conservation measures may mitigate impacts from future wildfire and habitat loss in higher-elevation areas.

In the near future (15 years), under Scenario 1, salamander detections contribute to the projected increase in overall future resiliency of 3 subunits. Although these gains in resiliency and distribution include the addition of a subunit within a currently unoccupied Unit, we do not expect substantial changes to current levels of genetic or ecological representation over the next 15 years. Salamanders are capable of persisting in all potential habitat types (i.e., ponderosa pine, mixed-conifer, and subalpine-fir) under continuation of current threats and increased survey efforts in Scenario 1. Further, under Scenario 1, the subunits in high or moderate resiliency are maintained in the same Units (Forest West, Forest North, and Preserve). Salamander recruitment, however, does expand from 3 into a 4th Unit (Forest North), suggesting the potential for a slight gain in genetic representation.

As we look further into the future under Scenarios 2 and 3 (100 years), regarding resiliency, no subunit will be in high condition overall, and overall condition will decrease in 7 subunits under Scenario 2 and 15 subunits under Scenario 3. Under Scenario 2 and 3, 16 of 34 subunits (47%) and 7 of 34 subunits (21%) are in moderate condition, respectively (Table 6.5, Table 6.6). Under Scenarios 2 and 3, moderate resiliency subunits are largely lumped together spatially across 3 Units (Forest West, Forest North, and Preserve), with one subunit in a fourth Unit (Monument) in Scenario 2. Although gains in moderate resiliency subunits suggest the potential for a slight gain in genetic representation, worsening climatic conditions are likely to reduce the amount of habitat capable of supporting salamander persistence and result in reduced salamander densities and range contractions, which will negatively influence genetic representation. Additionally, we predict that less favorable habitat is less likely (Scenario 2) or unlikely (Scenario 3) to support salamanders under the worsening climatic conditions predicted in these scenarios. Loss of and reductions in potential habitat decrease ecological representation under Scenarios 2 and 3. Future projections predict that salamanders are not detected in 14 of 18 (Scenario 2) and 24 of 28 (Scenario 3) subunits with low or very low future resiliency in over 15 years, suggesting salamanders may no longer persist in those subunits. Under Scenarios 2 and 3, no subunits are in high condition, and worsening climate conditions predicted under these scenarios result in the reduction and loss of available habitat, particularly in lower-elevation ponderosa pine-dominated forests. These conditions dominate vast areas within the Laboratory and Monument Units, suggesting that the greatest probability of persistence is in higher elevations in western portions of the species' range. Therefore, future genetic and ecological representation is negatively impacted and considered poor under these future scenarios. Because limited numbers of salamander locations persist within multiple subunits distributed throughout the species' range, maintaining remaining genetic diversity is crucial to maximizing future representation in Jemez Mountains salamanders.

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8 APPENDIX: DEVELOPING GIS DATA LAYERS AND ANALYSIS FOR JEMEZ MOUNTAINS SALAMANDER (*PLETHODON NEOMEXICANUS*) SPECIES STATUS ASSESSMENT (SSA) VERSION 1.0

8.1 *Background Information*

The Jemez Mountains salamander is endemic to the state of New Mexico and only found in and around the Jemez Mountains in northern part of the state, specifically in Los Alamos, Rio Arriba, and Sandoval counties. The majority of salamander habitat is located on federally managed lands including US Forest Service Santa Fe National Forest, US National Park Service Valles Caldera National Preserve and Bandelier National Monument, and US Department of Energy Los Alamos National Laboratory.

8.2 *Purpose*

This analysis provides geographic/spatial data and models focusing on forest conditions that could support habitat for the Jemez Mountains salamander (see section 2.4 Habitat of main SSA document). Forest models were created by the U.S. Fish & Wildlife Service (USFWS) with aid from the U.S. Forest Service and other SSA core team members. This Appendix will focus on the technical aspects of the GIS including

- Data types, acquisition, and applications related to Jemez Mountains salamander;
- Model construction and applications; and
- Geoprocessing and GIS tools used in the analysis.

8.3 *GIS Platform*

All GIS and remote sensing analyses, modeling and mapping work were done using ESRI Inc. ArcGIS 10.8.1 & ArcGIS Pro 2.9.

8.4 *GIS Analysis Results*

All results from the analysis, area summaries, and detailed discussions on data and models, as they apply to Jemez Mountains salamander current and future conditions, will reside in the main SSA report. A summary table of general area calculations will be later in this Appendix.

8.5 *Data Limitations*

All source datasets used were developed by entities outside the USFWS. Most data sets used are publicly available. The quality and accuracy of these data (ecological and spatial) may vary. Remotely sensed data products and large national datasets may contain inherent errors of omission and commission. Current land cover status may differ from the data displayed in the analysis. Actual, on-the-ground, quality and/or condition of mapped cover types is not addressed. No field verification or reviews of ancillary datasets/aerial imagery were done to verify the accuracy of the data. Most of the source raster data has a minimum spatial resolution of 30-meters.

Projections and Transformations

For this project, all data was projected into North American Albers Equal Area Conic, North American Datum 1983. Typically, the raster datasets are downloaded in WGS 84, or other geographic coordinate systems. All reprojections and transformations are accomplished using ArcMap Data Management tools.

8.6 *Analysis Area*

To identify this analysis area, we used historical and recent survey data in combination with subsurface geology information associated with GPS location data between 2000- 2021 (see section 3.2.2 Geographic Units and Subunits, in the main SSA document). Areas within the outer bound of the identified analysis area that extended below 2103 meters (m) (6900 feet [ft]) or included Tribal lands were subsequently removed. We divided the identified analysis area into five Geographic Units. The Units were further divided into subunits using features identified as likely barriers to salamander movement (Figure 8.1).

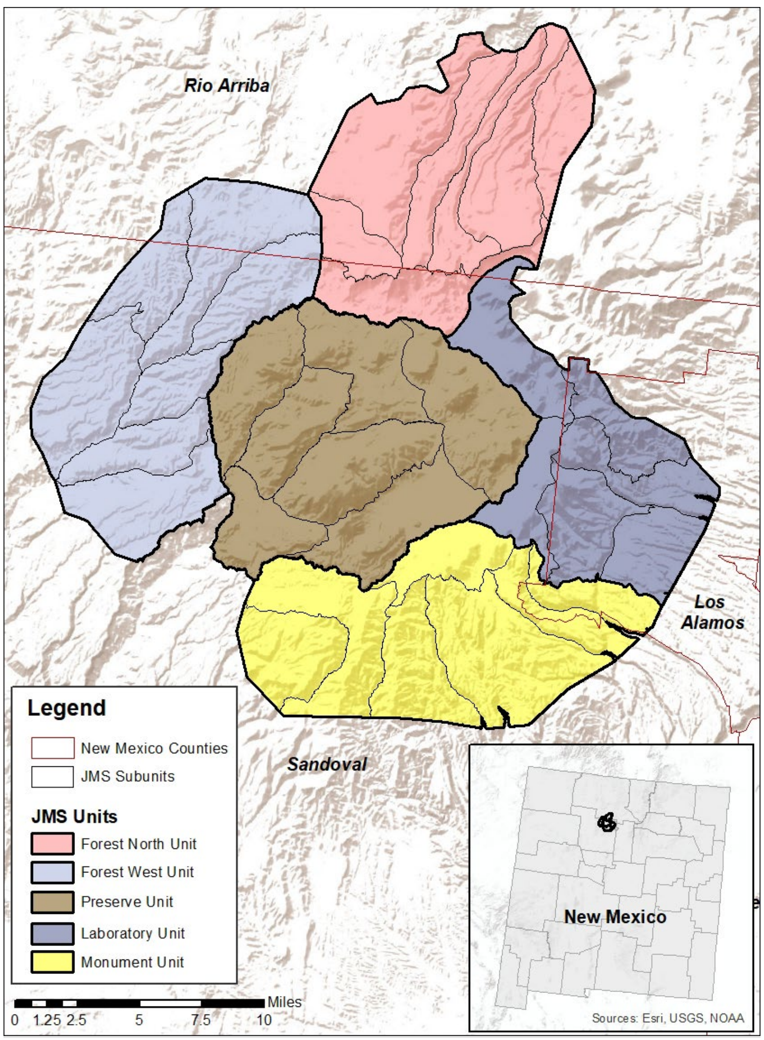

Figure 8.1. Jemez Mountains Salamander Analysis Area, Units and Subunits.

8.7 *General Habitat Conditions*

Jemez Mountains salamanders are endemic to the Jemez Mountains in the upper montane forest ranging in elevation of 2140-2900 m (7021-9514 ft) (Reagan 1972, p. 487). Salamanders are normally found in the forest edges along the montane meadows; they have also been found in high elevation meadows on rare occasions (Reagan 1972, p. 487). The forest structure contains mainly pine trees including white fir, Rocky Mountain maple (*Acer glabrum*), Engelmann spruce (*Picea engelmannii*), blue spruce (*Piceas pungens*), Ponderosa Pine (*Pinus ponderosa*), quaking aspen (*Populus tremuloides*), and Douglas fir (Reagan 1972, p. 487). Within this forest type salamanders were typically found on north facing steep slopes ranging from 5 to 36 degrees from horizontal, with the presence of underlying volcanic rock (Ramotnik and Scott 1988, p. 59; Reagan 1972, p. 488). Large concentrations of salamanders have been found within areas containing talus slopes likely due to the loose nature of the rocks and accessible refugia they provide (Reagan 1972, p. 488). Salamanders prefer decomposing pine logs, thin rocks, and burrows within talus slopes (Ramotnik and Scott 1988, p. 57; Carey 1987, p. 11).

8.8 *Limitations in Identifying These General Habitat Conditions with GIS Data Layers*

Due to the limited resolution of the land cover data used, and the diversity of habitat conditions the salamander can be found in, a forest condition model was developed to identify some of the important characteristics of habitat obtainable from readily available remotely sensed data sources. Future mapping and modeling efforts may be able to focus more on specific habitat characteristics, but with limited time and resources, this method was the most efficient in providing a spatial context for this SSA.

8.9 *Current Condition: Forest Condition Analysis*

8.9.1 *Forest Condition Analysis Developed for Jemez Mountains Salamander*

For this GIS analysis, forest condition model was defined by a specific spatial relationship derived from available/public datasets. This spatial analysis was designed to provide a landscape-scale depiction of the relationship between several different spatial data layers that are relevant to Jemez Mountains salamander. No attempt was made to define or describe actual, on-the-ground habitat. We recognize that this was a coarse forest vegetation model, and many other physical factors would be included for a more robust intensive habitat model. However, for our purposes at the range-wide scale, this analysis provides an adequate approximation on forest conditions on which to base our assessment.

8.9.2 *Environmental Predictor Layers Used for Suitable Vegetation Analysis*

Land Cover: The primary raster data layer for the analysis was 2016 USGS LANDFIRE (30-meter resolution). This layer provided detailed data on tree species and composition. It can be acquired from USGS LANDFIRE website.

- **Existing Vegetation Type (EVT)** – Complexes of plant communities representing NatureServe's terrestrial Ecological Systems classification.

Sentinel-2 Satellite Imagery: This multispectral dataset (10-meter resolution) provided information on general tree species and tree density. The source of the data is the European Space Agency. It is acquired through USGS Earth Explorer. The data is comprised of 13 individual multispectral bands, which can be combined to identify and enhance different aspects of vegetation. Imagery was collected from June and August of 2021. The June imagery was used for the analysis since herbaceous species were not in full photosynthesis and coniferous and deciduous trees were easily differentiated.

LiDAR: This layer provided data on tree height. The data was provided by the U.S. Forest Service Santa Fe National Forest. It was collected over a period from 2014 to 2019. The Canopy Height Model (a standard product of LiDAR data collection) was used for this analysis. Tree height was used as a proxy for tree size (old growth vs. new growth trees). Resolution of the original data was 0.6 meters. This was up-scaled mathematically using tools in ArcMap, to a more generalized 10-meter cell/pixel size. This was done to better "fit" with the other datasets and to save disc space and processing time.

8.9.3 *Initial Geoprocessing: Ranking Environmental Predictor Layers*

To best utilize the various data inputs, each layer was reclassified with a ranking description, giving it a relative "value" for its relationship or value to Jemez Mountains salamander. Detailed information on the reclassification of each layer and its application to the model will be described in detail below. The resolution for the forest condition model is 10 meters. The 30-meter LANDFIRE data was resampled to 10 meters to match with the other datasets.

Jemez Mountains salamander ranking terms and descriptions were developed by the SSA core team. Ranking terms were thought out carefully to provide the most accurate description of what the data and models are attempting to depict. Since it would be difficult to identify specific Jemez Mountains salamander habitat with the data being used, the reclassification of data and the modeling focused more on forest vegetation type and condition that would best suit Jemez Mountains Salamander activities. The terminology decided on by the SSA core team is as follows.

- **Favorable** – The highest probability of having proper forest conditions, based on the highest value of the data inputs.
- **Moderately Favorable** – A good probability of having proper forest conditions, based on higher mixed values of the data inputs.
- **Lest Favorable** - A lower probability of having proper forest conditions, based on lower values of the data inputs.
- **Non-Habitat** – Unlikely to have proper forest conditions, based on the lowest values of the data inputs. May contain disturbed/burned deciduous areas.
- **Not Analyzed**: Non- Forest or forested areas not associated with Jemez Mountains salamander.

Rankings were developed by the SSA core team based on the following criteria.

- Relationship to known/available salamander detection data.
- Detailed class descriptions from LANDFIRE.
- Expert knowledge and opinion from SSA core team members.

- Examination of other datasets (DEM; Slope/Aspect, USFS INREV)

USGS LANDFIRE Data

The 30-meter resolution dataset was reclassified to best describe vegetation type that would favor Jemez Mountains salamander activities. Though the dataset contains many other classes, only the ones shown here were used for the development of the forest condition model. All other classes were considered not to have enough value to use in this model (Table 8.1).

Table 8.1. Reclassified Existing Vegetation Type Woodland Classes.

EVT Value	EVT Name	JMS Rank Code
7052	Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland	100
7051	Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland	200
7055	Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland	300
7056	Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest and Woodland	300
7057	Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland	300
7054	Southern Rocky Mountain Ponderosa Pine Woodland	400
7117	Southern Rocky Mountain Ponderosa Pine Savanna	400
7011	Rocky Mountain Aspen Forest and Woodland	500
7061	Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland	500
7016	Colorado Plateau Pinyon-Juniper Woodland	600
7059	Southern Rocky Mountain Pinyon-Juniper Woodland	600
7119	Southern Rocky Mountain Juniper Woodland and Savanna	600
7193	Recently Logged-Tree Cover	700
7197	Recently Burned-Tree Cover	700
7200	Recently Disturbed Other-Tree Cover	700

The ranked classes are then grouped for the input layer (Table 8.2).

Table 8.2. Reclassified and Grouped Existing Vegetation Type Woodland Classes.

EVT Group	Rank Code	Model Representation
Mesic Mixed Conifer	100	Most Favorable
Dry-Mesic Mixed Conifer	200	
All Sub-Alpine Spruce/Fir	300	
Ponderosa Pine	400	
Aspen & Aspen Mixed Con.	500	
Shrub (Juniper/Pinion)	600	Least Favorable
Disturbed	700	Disturbed

Sentinel-2 Satellite Imagery

To maximize the utilization of the imagery, a color infrared image was created by combining bands B8, B4, and B3. This was done in ArcMap using ArcToolbox/Data Management/Raster/Composite Bands tool. Color infrared imagery is used for differentiating coniferous and deciduous trees (Figure 8.2). The resulting color infrared image was then classified using ArcToolbox/Spatial Analyst/Multivariate/ISO Cluster Unsupervised Classification (Figure 8.3). This automatically groups similar pixels together. A 12-class output was selected to separate different signatures but not create too much "noise" or class variability in the final output. It also tended to differentiate the signatures of tree densities. Identifying denser forested areas compared with sparser areas was the important factor in using this data layer (Table 8.3).

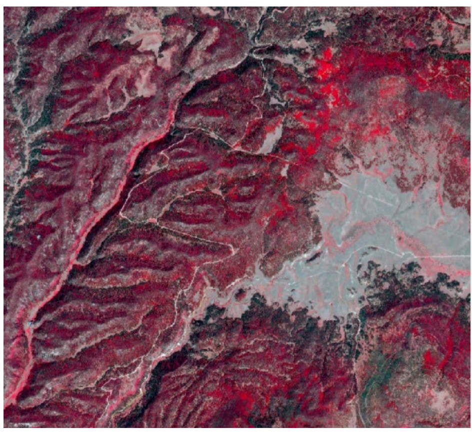

Figure 8.2. Example of color infrared image Jemez Mountains, New Mexico.

Figure 8.3. Example of A 12-class ISO Cluster Unsupervised Classification, Jemez Mountains, New Mexico.

Table 8.3. Interpreted landscape descriptions of the 12-class classification.

Classvalue	General Description	JMS Rank Code
0	Sparser Forest-Mostly Coniferous	20
1	Denser Forest-Mostly Coniferous	10
2	Roads/Sparse Vegetation (Bright)	0
3	Grass/Shrub	0
4	Conifer/Deciduous Mix	30
5	Grass	0
6	Grass/Roads/Sparse Vegetation (Bright)	0
7	Deciduous Tree & Shrub (Burn re-growth too)	40
8	Grass/Wet Meadow	0
9	Very Sparse Tree/shrub/Herbaceous	50
10	Grass/Roads	0
11	Roads/Sparse Vegetation (Bright)	0

The usable classes were then grouped by their ranking (Table 8.4).

Table 8.4. Grouped and ranked, most favorable to least favorable, Sentinel classes for the model input.

Sentinel Class	Rank Code	Model Representation
Conifer-Dense	10	Most Favorable
Conifer-Sparse	20	
Con/Dec Mix	30	
Deciduous/Disturbed	40	
Very Sparse Tree/shrub/Herbaceous	50	Least Favorable
Non-Forest	0	N/A

LiDAR Imagery

LiDAR imagery was used to serve as a proxy for tree size and age. This assumes, in general, that the taller trees will represent larger older trees. The LiDAR canopy height model was used for this. The original data was at 0.6-meter resolution (Figure 8.4). This basically identifies each tree individually. For this analysis, the level of detail was too much. To adapt this layer to work with the other datasets, the tree heights were grouped together and reclassified (Table 8.5).

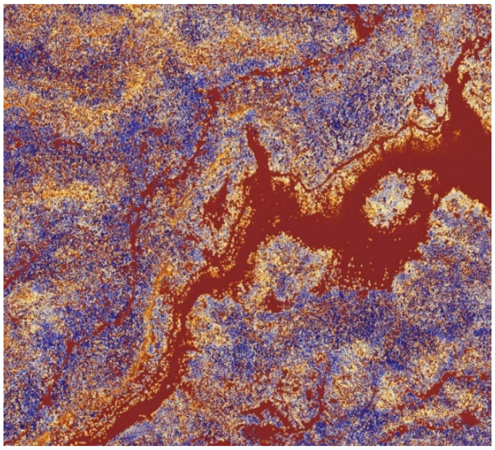

Figure 8.4. LiDAR data at original 0.6-meter pixel size. Blue tones are highest, tan tones intermediate, and brown tones the lowest.

Table 8.5. Grouped and ranked, most favorable to least favorable, LiDAR classes for the model input.

Height	Rank Code	Model Representation
100 ft +	1	Most Favorable
50-99 ft	2	
20-49 ft	3	
5-19 ft	4	
0-4 ft	5	Least Favorable

Once grouped and reclassified, the data was resampled to a 10-meter pixel size, using ArcToolbox/Data Management/Raster/Raster Processing/Resample tool. The Bilinear resampling method was used (Figure 8.5).

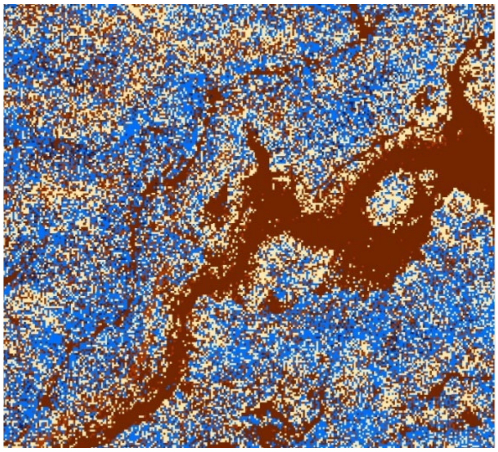

Figure 8.5. LiDAR data resampled to 10-meter pixel size. Blue tones are highest, tan tones intermediate, and brown tones the lowest.

8.9.4 *Geoprocessing: Constructing an Integer-based GIS model with the Data Layers*

In this model, each ranking from each new reclassified layer is assigned a unique integer value (Table 8.6). These values were combined to calculate an overall value using the Cell Statistics Tool in ArcToolbox/Spatial Analyst/Local.

Table 8.6. Model Structure with Integer Values by Layer.

LANDFIRE EVT Group	Rank Code
Mesic Mixed Conifer	100
Dry-Mesic Mixed Conifer	200
All Sub-Alpine Spruce/Fir	300
Ponderosa Pine	400
Aspen & Aspen Mixed Con.	500
Shrub (Juniper/Pinion)	600
Disturbed	700

Sentinel Class	Rank Code
Dense-Mostly Con.	10
Sparser-Mostly Con.	20
Con/Dec Mix	30
Deciduous/Disturbed	40
VS Trees/Herb*	50

Height	Rank Code
100 ft +	1
50-99 ft	2
20-49 ft	3
5-19 ft	4
0-4 ft	5

Cell Statistics is a tool in ArcMap/Spatial Analyst which calculates the cell values of two or more rasters. Using the "SUM" function, the tool will add all cell values spatially overlaying each other (Figure 8.6). Raster cells are set into alignment as they are reclassified or resampled, using the "SnapRaster" processing environment. Each square represents a pixel from each layer.

LANDFIRE EVT

100	300	100	200
100	200	200	400
200	400	400	400
400	400	700	700

+

Sentinel

10	10	20	20
10	20	20	20
10	20	30	50
20	50	40	40

+

LiDAR

1	1	3	3
1	2	2	2
2	2	3	4
2	3	4	4

=

Combined Output

111	311	123	223
111	222	222	422
212	422	433	454
422	453	744	744

Figure 8.6. Schematic of Cell Statistic tool, inputs and output for all reclassified layers.

With this model structure, the best of all combinations would be 111. This represents the most favorable conditions from each layer. Just as 744 would represent the least favorable conditions. Of course, there are many other combinations to consider by the SSA core team.

8.9.5 *Output Combined Output Ranking*

The combined value was ranked by the SSA core team into a final classification (Table 8.7). Color designations were used to help visualize the ranking process (Colors subject to change). The final rankings are described several sections above.

Table 8.7. Final classification with color designations.

	Favorable
	Moderately Favorable
	Least Favorable
	Non-Habitat (Could contain disturbed/burned, deciduous)
	Non-Forest or Forest removed from Analysis

The greyed-out boxes in Table 8.7 represent non-forest or forest removed from analysis. Color scheme was used for mapping. The combined output layer now has values from each of the input layers. The SSA core team went through each combination to give each new combined value an overall rank. Though the model is not intended to specifically identify Jemez Mountains Salamander habitat, the SSA core team took into consideration each element of the combined value, and how that might relate to the salamander (Table 8.8). The combined output values spatial distribution was then combined with the salamander units and subunits to generate Figure 8.7.

Table 8.8. Combined output values for Jemez Mountains salamander forest condition model.

111	121	131	141	151
112	122	132	142	152
113	123	133	143	153
114	124	134	144	154
115	125	135	145	155

511	521	531	541	551
512	522	532	542	552
513	523	533	543	553
514	524	534	544	554
515	525	535	545	555

211	221	231	241	251
212	222	232	242	252
213	223	233	243	253
214	224	234	244	254
215	225	235	245	255

611	621	631	641	651
612	622	632	642	652
613	623	633	643	653
614	624	634	644	654
615	625	635	645	655

311	321	331	341	351
312	322	332	342	352
313	323	333	343	353
314	324	334	344	354
315	325	335	345	355

711	721	731	741	751
712	722	732	742	752
713	723	733	743	753
714	724	734	744	754
715	725	735	745	755

411	421	431	441	451
412	422	432	442	452
413	423	433	443	453
414	424	434	444	454
415	425	435	445	455

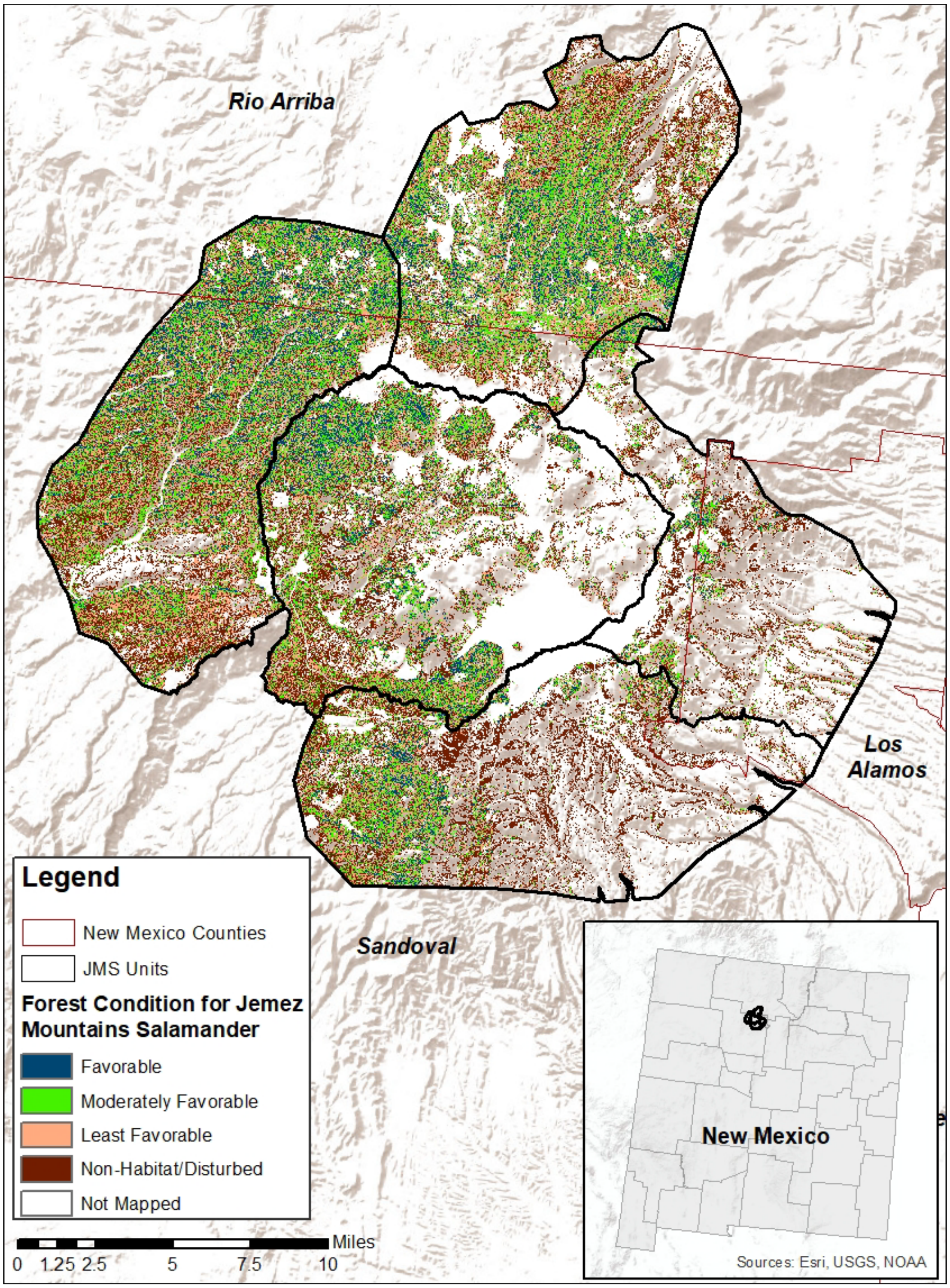

Figure 8.7. Spatial distribution of classified Forest Model for Jemez Mountains Salamander.

8.9.6 *Other Applications for Forest Condition Model*

Though the primary intent of the model was to identify favorable areas where Jemez Mountains Salamander may potentially be found, the model may also provide information on younger/new growth forest areas (which could harbor more favorable forest conditions in the future), areas identified in the model as favorable or moderately favorable that have little or no surveys, and disturbed/damaged areas suitable for restoration.

8.9.7 *Final Acreage Output Results of Spatial Data*

Below are the acreage summaries for the final spatial analysis output. All discussions on usage, relationships, and implications to the Jemez Mountains Salamander can be found in the main SSA report (Table 8.9).

Table 8.9. Acreage summaries, by Unit, for the Jemez Mountains salamander.

JMS Class	Forest North	Laboratory	Monument	Forest West	Preserve	Totals
Favorable	6,163	775	2,035	7,995	4,619	21,586
Mod. Fav.	10,208	1,627	3,911	12,212	7,445	35,402
Least Fav.	13,838	2,394	5,005	15,322	9,144	45,703
Non-Habitat	9,987	5,665	13,246	14,461	11,672	55,031
Not Mapped	18,792	31,350	36,229	11,978	35,847	134,196
Totals	58,988	41,810	60,427	61,967	68,727	291,919

8.10 *Current Condition: Wildfire Vulnerability Model*

To aid the SSA core team in the development of condition categories dealing with the impact of fire on known detection locations, an analysis was done to look at the relationship of these locations with recent and historical wildfire data (see Data Sources below). Detection locations collected by Federal, State, and academic entities, over the last 14 years (from 2008-2021) were used. A GIS layer was designed using fire severity data, detection points, the forest condition model, and the Unit/Subunit layers.

Data Sources:

- **Fire Severity:** Burned Area Reflectance Classification (BARC) and Cerro Pelado Soil Burn Severity data. Both datasets were provided by the U.S. Forest Service.
- BARC data time span is 1996-2021. Cerro Pelado data from June of 2022.
- **Salamander Detection Points:** Salamander detection points covering the last 14 years (from 2008-2021), collected by federal, state, and academic entities.
- **Forest Condition Model:** Created for this SSA. Discussed above.
- **Unit/Subunit Layer:** Created for this SSA. Discussed above and in main SSA report, section 3.2.2 Geographic Units and Subunits.

Geoprocessing: Reclassification of the Data

The BARC data was reclassified to identify only moderate and severe fire intensity. Lower intensities were not considered for this analysis (See section 4.1.2 Habitat Resiliency Factors, in main SSA report). The Cerro Pelado Soil Burn Severity data was integrated with the BARC data. The BARC data was clipped by the Cerro Pelado data and removed. The Cerro Pelado data was then merged with the BARC data. This was done because the Cerro Pelado data was more recent than the BARC data.

Each Forest Unit and Subunit were given numeric designations, to identify each uniquely. The Forest Condition model classes were also given unique numbers. The model structure is included in Table 8.10 below.

Table 8.10. Fire Severity Model Structure. Rank codes for each layer.

Fire Severity	Rank Code
Moderate	1000
Severe	2000

Unit Designation	Rank Code
Forest North	100
Laboratory	200
Monument	300
Forest West	400
Preserve	500

Subunits	Rank Code
Within each Unit	10-70

Forest Condition	Rank Code
Favorable	1
Moderately Favorable	2
Least Favorable	3
Non-Habitat	4
Not Mapped	9

As with the Forest Condition Model, the layers are combined using the Cell Statistics tool in ArcMap/Spatial Analyst which calculates the cell values of two or more rasters. Using the "SUM" function, the tool will add all cell values spatially overlaying each other. This is explained in more detail earlier in this appendix. The output of the Cell Statistics will provide fire severity and forest condition for each Unit/Subunit (Figure 8.8).

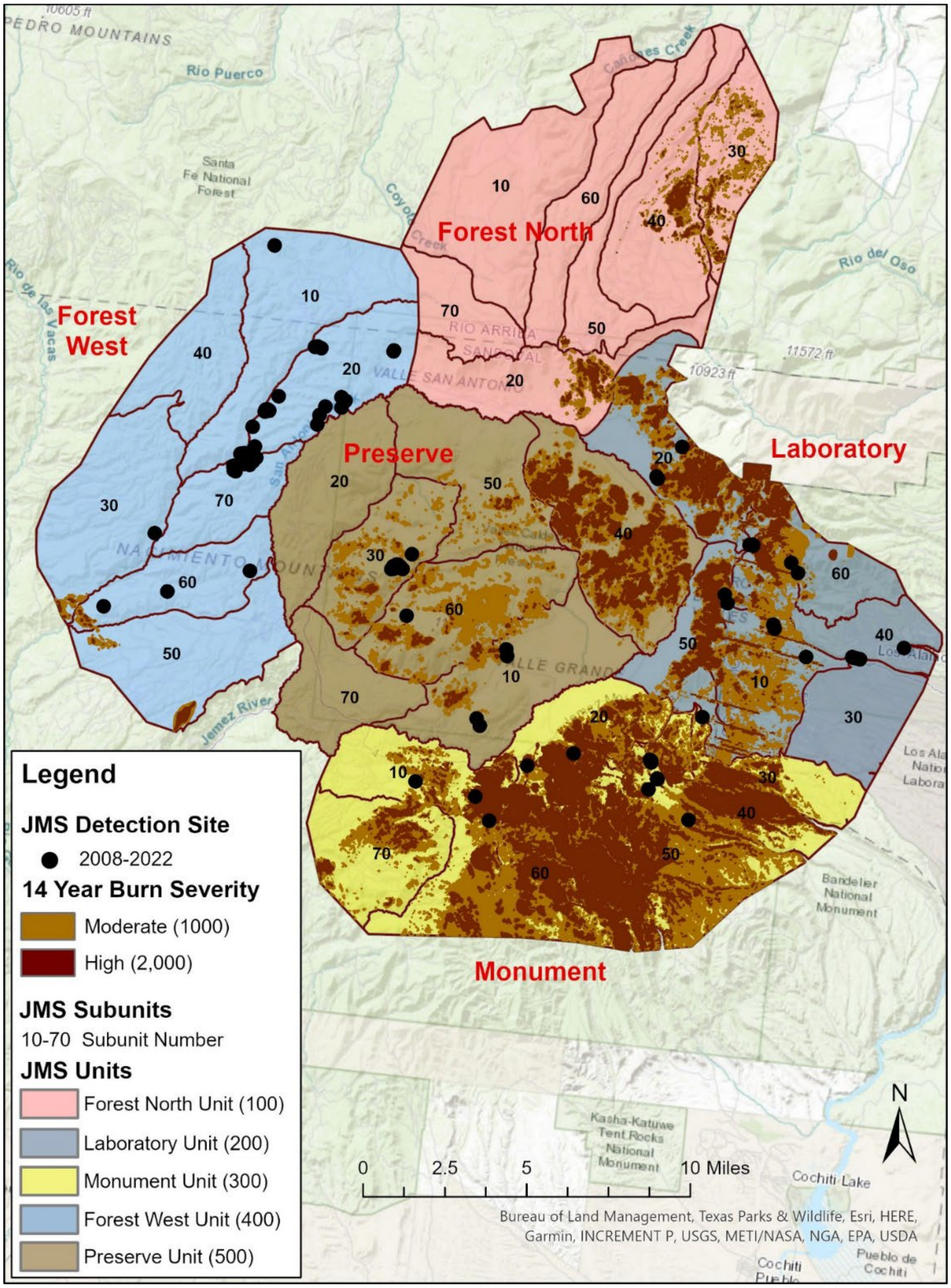

Figure 8.8. Burn severity layer with Units and Subunits, and detection locations. Forest Condition model not displayed. Point features over-sized for display.

8.10.1 *Geoprocessing: Extracting Reclassified Values to Points*

Next, the wildfire vulnerability model final combined values were extracted for each detection point using the Extract by Points tool in ArcMap Spatial Analyst. The results for the GIS are shown below (Table 8.11). Note: there were no detection locations in the Forest North Unit in the last 14 years (from 2008-2021).

Table 8.11. Detection locations impacted by moderate or severe fire over the last 14 years (from 2008-2021).

Unit	Sub Unit	# Points-No Fire	# Points-Fire	Total
Laboratory-200	10	2	2	4
	20	1	3	4
	30	6	0	6
	40	3	2	5
	60	2	0	2
		14	7	21

Forest Type	# Points
1	
2	2
3	4
4	2
9	13
	21

Unit	Sub Unit	# Points-No Fire	# Points-Fire	Total
Monument-300	10	1	2	3
	20	0	1	1
	30	1	0	1
	40	3	4	7
	50	2	2	4
		7	9	16

Forest Type	# Points
1	0
2	2
3	1
4	6
9	7
	16

Unit	Sub Unit	# Points-No Fire	# Points-Fire	Total
Forest West-400	10	4	0	4
	20	30	0	30
	30	3	0	3
	60	3	0	3
	70	70	0	70
		110	0	110

Forest Type	# Points
1	32
2	34
3	31
4	7
9	6
	110

Unit	Sub Unit	# Points-No Fire	# Points-Fire	Total
Preserve-500	10	4	0	4
	30	36	0	36
	60	1	0	1
		41	0	41

Forest Type	# Points
1	2
2	10
3	15
4	8
9	6
	41

8.11 *Conclusion*

This report is a brief summation of the GIS data analysis (data layer usage and geoprocessing techniques) devised to help provide a spatial understanding of the location and extent of forest conditions and wildfire impacts for the Jemez Mountains Salamander. The main SSA report will provide more detailed discussions on the applications of these analyses.

8.12 *Literature Cited*

See chapter 7 LITERATURE CITED, in main SSA report.