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# THREE CASE STUDIES OF THE EFFECT OF WILDFIRE ON THE JEMEZ MOUNTAINS SALAMANDER (*PLETHODON NEOMEXICANUS*): MICROHABITAT TEMPERATURES, SIZE DISTRIBUTIONS, AND A HISTORICAL LOCALITY PERSPECTIVE

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ABSTRACT—Fire regimes in North America, including the American Southwest, have undergone relatively dramatic shifts in the last century, resulting in novel stand-replacing fires, which are changing landscapes in unprecedented ways. We investigated some possible effects of these landscape changes on a terrestrial plethodontid salamander (*Plethodon neomexicanus*). We investigated microhabitat temperatures in 4 burn-severity types following recent fires. Temperatures were significantly greater in high-severity and moderate-severity burn areas than in low-severity and unburned areas. We present presence-absence data from 4 burn-severity types that were previously documented as having salamanders present. The proportions of presence and absence were similar for all severity types. Finally, we used data from a 9-year demographic study of *P. neomexicanus* from 2 locations, where one location was burned in a wildfire halfway through the study, to measure possible effects of fire. We compared salamander size distributions and body condition pre-fire and post-fire within the burned site, and the unburned site was used as a reference location. Salamanders at the burned site had a shift in size distribution, with an increase in observed juveniles and a decrease in observed adults 2 y post-fire relative to itself. No significant changes were measured at the unburned site. We did not observe a significant effect in salamander body condition. Overall, we conclude that salamander surveys are valuable for determining presence-absence, but alone are ineffective and not appropriate for monitoring or measuring populations after a disturbance. We suggest that future studies investigating the effects of disturbance on terrestrial plethodontid salamanders use size distribution and potentially body condition data to monitor for effects within populations, in conjunction with measuring environmental parameters for understanding causal agents.

RESUMEN—El patrón de incendios en América del Norte, incluyendo el suroeste de los Estados Unidos, ha cambiado dramáticamente durante el último siglo, resultando en fuegos insólitos que reemplazan bosques enteros y que cambian el paisaje en maneras jamás vistas. Investigamos algunos de los posibles efectos de estos cambios del paisaje en una salamandra terrestre (Plethodontidae: *Plethodon neomexicanus*). Investigamos temperaturas de microhábitat en 4 tipos de severidad de quema después de incendios recientes. Las temperaturas fueron significativamente más altas en áreas de quema de alta y de mediana severidad que en áreas de baja severidad de fuego o no incendiadas. Presentamos datos de presencia y ausencia en áreas de los 4 tipos de severidad de fuego donde previamente se documentó la presencia de salamandras. Las proporciones de presencia y ausencia fueron similares en todos los niveles de severidad. Finalmente, usamos datos de un estudio demográfico de 9 años de *P. neomexicanus* de 2 localidades, donde una de ellas fue quemada por un fuego natural a mitad del estudio, para medir los posibles efectos del fuego. Comparamos las distribuciones de los tamaños corporales de las salamandras y su condición corporal tanto antes como después del fuego dentro del área quemada, y el área no quemada fue usada como localidad de referencia. Las salamandras del sitio quemado cambiaron su distribución de tamaños corporales, con un aumento en juveniles observados y un decremento en adultos observados 2 años después del fuego en contraste consigo mismo. No se midieron cambios significativos en el sitio no quemado. No observamos un efecto significativo en la condición corporal de las salamandras. En conclusión, los muestreos de salamandras son herramientas de valor para determinar su presencia o ausencia, pero solos no son efectivos ni apropiados para monitorear o medir poblaciones después de una perturbación. Sugerimos que investigaciones futuras de efectos de perturbación en salamandras terrestres (Plethodontidae) usen tanto la distribución de tamaños corporales, y potencialmente la condición corporal, para monitorear efectos dentro de poblaciones, como parámetros ambientales para comprender agentes causales.

Fire regimes in North America have undergone relatively dramatic shifts in the last century (Agee, 1993; Covington and Moore, 1994; Swetnam and Baisan, 1996; Allen, 2002). Often associated with shifts in fire regimes are changes in forest structure and composition (Allen, 1989; Covington and Moore, 1994; Swetnam et al., 1999). In the southwestern United States, anthropogenic influences, such as effective fire suppression, logging, and extensive livestock grazing (deBuys, 1985; Covington and Moore, 1994; Touchan et al., 1996; Allen et al., 2002), combined with natural factors, such as the influence of the Southern Oscillation and other climatic events (Swetnam, 1990; Swetnam and Betancourt, 1990; Touchan et al., 1996; Swetnam and Betancourt, 1998), have lead to dramatic fire regime shifts and associated forest structure change; the results are stand-replacing wildfires novel to landscapes. Similar changes in fire regimes and resultant large-scale wildfires have occurred in other parts of the United States (Sharitz et al., 1992; Agee, 1993; Morgan et al., 1996). With the increase of novel disturbances across landscapes, studies are needed to address their ecological effects.

We have studied aspects of the effect of wildfire on the Jemez Mountains salamander (*Plethodon neomexicanus*), a state-threatened, endemic, terrestrial salamander of north-central New Mexico. Ecological research on terrestrial plethodontid salamanders, often because of their subterranean and elusive habits, is well known for being difficult. Populations that occur with, or have declined to, small numbers of individuals exacerbate the situation. Inherent difficulties in studying disturbance effects in terrestrial plethodontid salamanders can lead to controversies (Ash and Bruce, 1994; Petranka, 1994, 1999), ambiguous results (i.e., Kirkland et al., 1996; Cole et al., 1997), and a general paucity of data upon which to base decisions for management and conservation. Furthermore, studies addressing the effects of wildfire on amphibian populations are few, often with results that are poorly understood (for review, see Pilliod et al., 2003). Based on our studies of wildfire and *P. neomexicanus* in the Jemez Mountains, we make suggestions to other researchers investigating the effects of landscape disturbance on terrestrial plethodontid salamanders.

*Plethodon neomexicanus* (Caudata: Plethodontidae) is a lungless, completely terrestrial salamander that is generally located in mixed-conifer forest at an elevation between 2,200 and 2,900 m (Degenhardt et al., 1996) in the Jemez Mountains of northern New Mexico. This species spends much of its life underground, but can be found at the surface when conditions are warm and wet, typically July through September. Presently, a low-elevation, semiarid environment surrounds the Jemez Mountains, restricting *P. neomexicanus* to this small mountain range (approximately 35 × 30 km).

Beginning in 1977 with the La Mesa Fire (15,444 acres), the Jemez Mountains began to experience stand-replacing fires on an unprecedented scale. Fires of similar magnitude continued with the Dome Fire in 1996 (16,516 acres), the Oso Fire in 1997 (6,508 acres), the Cerro Grande Fire in 2000 (42,971 acres), and the Lakes Fork Complex in 2002 (4,026 acres; acreage provided by K. Beeley, pers. comm.).

An interagency Burned Area Emergency Rehabilitation (BAER) Team documents the severity-type and boundaries of some wildfires. GIS data provided by 1996 and 2000 BAER Teams (in litt.) indicated that in 2 of the recent fires (Dome, Cerro Grande) more than one-third of the habitat where most *P. neomexicanus* are known to occur burned with moderate-severity and high-severity (25 to 100% of stand basal area killed).

Holman (1995) suggested that herpetofauna of the Rocky Mountains has remained relatively unchanged from the Pleistocene into Holocene times. The extensive dendrochronological fire history data from the Jemez Mountains (including multiple sites currently occupied by *P. neomexicanus*) indicate that, prior to fire suppression (ca. 1890s) back into at least the 1500s, frequent, widespread fire activity characterized most Jemez forest types. These fires ranged from extensive low-intensity surface fires in ponderosa pine (*Pinus ponderosa*) and drier mixed-conifer forests to mixed-severity patterns of surface and small-scale, patchy crown fires in more mesic mixed-conifer and spruce-fir (*Picea-Abies*) forests (Allen, 1989, 2002; Touchan et al., 1996; Swetnam et al., 1999). Thus, it can be inferred that *P. neomexicanus* has persisted in the presence of widespread low-intensity fire and smaller, patchy crown fires for at least several hundred salamander generations. The recent spate of large stand-replacing fires in the Jemez Mountains has occurred during extremely dry conditions, generally before summer rains and salamander surface activity, so direct salamander fatalities from wildfire are unlikely. However, post-fire microhabitats at the surface have, nonetheless, been greatly altered, and the indirect effects of such severe fires remain unknown.

We present 3 studies that address different aspects of measuring an effect of wildfire on a terrestrial salamander. In Study 1, we quantified changes in microhabitat surface conditions resulting from wildfire. Temperature is known to be an important environmental variable for terrestrial plethodontid salamanders affecting desiccation and hydration, metabolism, oxygen consumption, and other physiological functions (Rome et al., 1991; Shoemaker et al., 1991). We measured microhabitat temperatures in 2001 under potential cover objects in areas subjected to 4 burn-severities. In Study 2, we sought to measure differences in salamander populations in areas subjected to the same burn-severities by comparing numbers of salamanders encountered, presence-absence of salamanders, and rate of capture of salamanders. However, recent authors (Hyde and Simons, 2001; MacKenzie and Kendall, 2002; Schmidt, 2003) have identified unacceptable assumptions that create problems when direct comparisons of numbers or rates of salamanders found are made without adjusting for detection probabilities. We did not measure detection probabilities and our field observations confirm that the probabilities likely varied between the different burn-severities; thus, our data are limited to presence-absence. Finally, in Study 3, we looked for responses in size distributions and body condition of salamanders at a single well-studied location, pre-fire and post-fire (1996 Dome Fire), and in an unburned reference population.

METHODS—*Study 1*—To measure potential changes in microhabitat temperature in areas affected by different burn-severities, we placed 18 thermal data-loggers with high-accuracy temperature probes (HOBO H8 Outdoor/Industrial 4-channel external; Onset Inc., Pocasset, Massachusetts) under potential salamander cover objects. The 18 data-loggers were placed at previously known salamander localities, not under exact cover objects with salamanders.

Burn-severity types of the Cerro Grande Fire (unburned, here, representing fire-suppressed forests; low-severity, burned with <25% of basal stand area (SBA) killed; moderate-severity, 25 to 80% SBA killed; high-severity, >80% SBA killed) were documented and mapped by the 2000 Cerro Grande BAER Team (in litt.). The 18 data-loggers were distributed among burn-severity types where salamanders were previously documented (unburned, $n = 3$; low-severity, $n = 3$; moderate-severity, $n = 3$; and high-severity, $n = 8$; one data logger was placed in an area burned with high-severity known to have salamanders pre-fire and post-fire of the 1996 Dome Fire). A temperature probe was placed approximately 4 cm under the surface of the soil under a potential cover object (rock or log). The aspect, slope, cover object type, and canopy cover for each data-logger are reported in Table 1. Three data-loggers (2 in moderate-severity, 1 in low-severity) malfunctioned or were disturbed by wildlife and are not included in the results. Temperature data were collected at approximately 10-minute intervals, 24 h/d, throughout the period of salamander surface activity (July through September) in 2001. Minimum and maximum daily temperatures were recorded, and average 24-h daily temperatures were computed for each data-logger location. The 24-h daily temperature data from each data-logger were averaged by burn-severity type. A paired *t*-test (SAS, 1999) was used to test for differences between each burn-severity type and the thermal preferendum for this species. A species thermal preferendum is the narrow range of temperatures that defines its normal activity range (Spotila, 1972). Williams (1972) reported the mean ($\pm SE$) microhabitat temperatures of 577 *P. neomexicanus* salamanders as 12.5 ± 0.06°C (by placing a mercury thermometer under a cover object with a salamander, in unburned, fire-suppressed forests). We used 12.5°C as the thermal preferendum for this species.

*Study 2*—We present salamander presence-absence data in a context of revisited historical localities, with burn-severities as a subset of those data. Historical localities were areas where salamanders had been detected sometime prior to 2000 and were revisited in 2000, 2001, or both. There were 3 locations that were new (i.e., not historical); however, they were in the vicinity of historical localities. Salamanders were detected at all 3 new localities in 2000 and are grouped herein with historical localities.

We surveyed historical localities affected by 4 previously defined burn-severities in the 2000 Cerro Grande Fire, as well as a location that was burned with a mosaic pattern of moderate-severity and high-severity in the 1996 Dome Fire. We used a standardized 2-person-hour Time Constrained Search (TCS) to survey for salamanders (Campbell and Christman, 1982). The 2-person-hour TCS involved searching for salamanders by looking in large decomposing logs and under cover objects (logs, rocks, bark, branches, moss mats) for 2-person-hours (total time per survey = 2 h/number of searchers) and recorded all salamanders encountered.

TABLE 1—Site descriptions and cover types for temperature data-logger placements distributed among burn-severity types (defined in text) following the 2000 Cerro Grande Fire in New Mexico where the Jemez Mountains salamander (*Plethodon neomexicanus*) was previously documented. One data logger was placed in an area burned with high-severity known to have salamanders pre-fire and post-fire for the 1996 Dome Fire.

| Burn severity | Percent overstory | Aspect (°) | Slope (%) | Cover type | Cover size (cm) |
|---|---|---|---|---|---|
| Unburned | 60 | 168 | 4 | Woody debris | 36 × 10 × 3 |
| Unburned | 69 | 39 | 23 | Mossy log | 52 × 8 |
| Unburned | 54 | 258 | 57 | Rock | 36 × 40 |
| Low | 71 | 34 | 78 | Rock | 41 × 25 |
| Low | 69 | 98 | 21 | Rock | 24 × 20 |
| Low* | 90 | 34 | 42 | Burnt log | 250 × 30 |
| Moderate | 37 | 166 | 8 | Rock | 30 × 10 |
| Moderate* | 70 | 94 | 34 | Burnt log | 150 × 15 |
| Moderate* | 67 | 3 | 44 | Rock | 8 × 10 |
| High | 18 | 214 | 42 | Rock | 18 × 9 |
| High | 11 | 240 | 23 | Rock | 16 × 10 |
| High | 10 | 228 | 31 | Rock | 18 × 18 |
| High | 14 | 284 | 32 | Rock | 21 × 19 |
| High | 6 | 110 | 11 | Rock | 10 × 8 |
| High | 14 | 132 | 52 | Rock | 25 × 20 |
| High | 18 | 21 | 33 | Rock | 21 × 24 |
| High | 13 | 71 | 12 | Burnt log | 100 × 20 |
| Dome Fire | 56 | 210 | 59 | Rock | 28 × 10 |

* Data collected from these data-loggers were not used because the data-loggers were disturbed by wildlife or malfunctioned.

Cover objects were replaced to minimize habitat disturbance.

Salamander surveys were conducted during daytime hours, when surface microhabitat conditions were wet during salamander surface activity period from July through October. Previously, nocturnal surveys, artificial cover board arrays, and pitfall trapping of *P. neomexicanus* were unsuccessful and were not used.

*Study 3*—A salamander activity study, consisting of four 50 × 50 m activity-plots, was started in 1992 to study the demography of *P. neomexicanus.* The 4 activity-plots were set up in 2 locations; each location consisted of a plot on a steep slope and a plot on a flat slope adjacent to the steep slope. The data from the 2 plots at each location were combined because each represents one population. One of the 2 locations (Dome) was burned in a mosaic pattern with moderate-severity and high-severity in the 1996 Dome Fire, whereas the other location (Posos) did not burn. This unplanned experiment allowed for a comparison of size distributions and body condition of salamanders pre-fire and post-fire at the Dome location, as well as providing an unburned reference location. During the activity-plot study, every possible cover object within the plots was mapped and checked for salamanders during each survey session. Salamander surveys were conducted during daytime hours and only when surface conditions were wet and optimal for observing salamanders. Plots were visited in 1991, 1992, 1994, and 1997 to 2000, with 1 to 3 survey sessions conducted during the period of salamander surface activity each year, dependent upon moisture conditions and availability of personnel. Salamanders were anesthetized with tricaine methanesulfonate (MS222), measured with digital calipers to 0.1 mm, examined for tail condition (undamaged, damaged, stump), and weighed to 0.1 g with a 5-g Pesola spring-scale on a stand. Salamander body measurements included snout–vent length (SVL) and tail length; sex was not determined. Individual salamanders were uniquely marked subcutaneously with either a pit-tag or fluorescent elastimer. After complete recovery from the anesthetic, salamanders were returned to the exact point of capture.

To investigate size distributions, we used a Tukey test to make multiple comparisons of salamander SVL between years at each location ($\alpha = 0.05$; SAS, 1999). Repeated measurements of individuals recaptured within the same year were not used. Body condition was measured by regressing the natural log of mass onto the natural log of total length, to adjust the mass for total length, using an analysis of covariance (ANCOVA; SAS, 1999) for salamanders with undamaged tails; recaptured salamanders were not used. Sample size of recaptured salamanders was small and not analyzed. Finally, we visually compared the injury rate of salamanders (comparison of proportions salamanders with undamaged tails to those with damaged and stumped tails) to look for a trend in tail damage pre-fire and post-fire at the Dome location, as well as relative to the Posos location. Tail damage could be an indicator of predation or competition in salamanders, as well as an indicator of salamander condition.

RESULTS—*Study 1*—The 24-h average daily temperatures of microhabitats during 2001 were

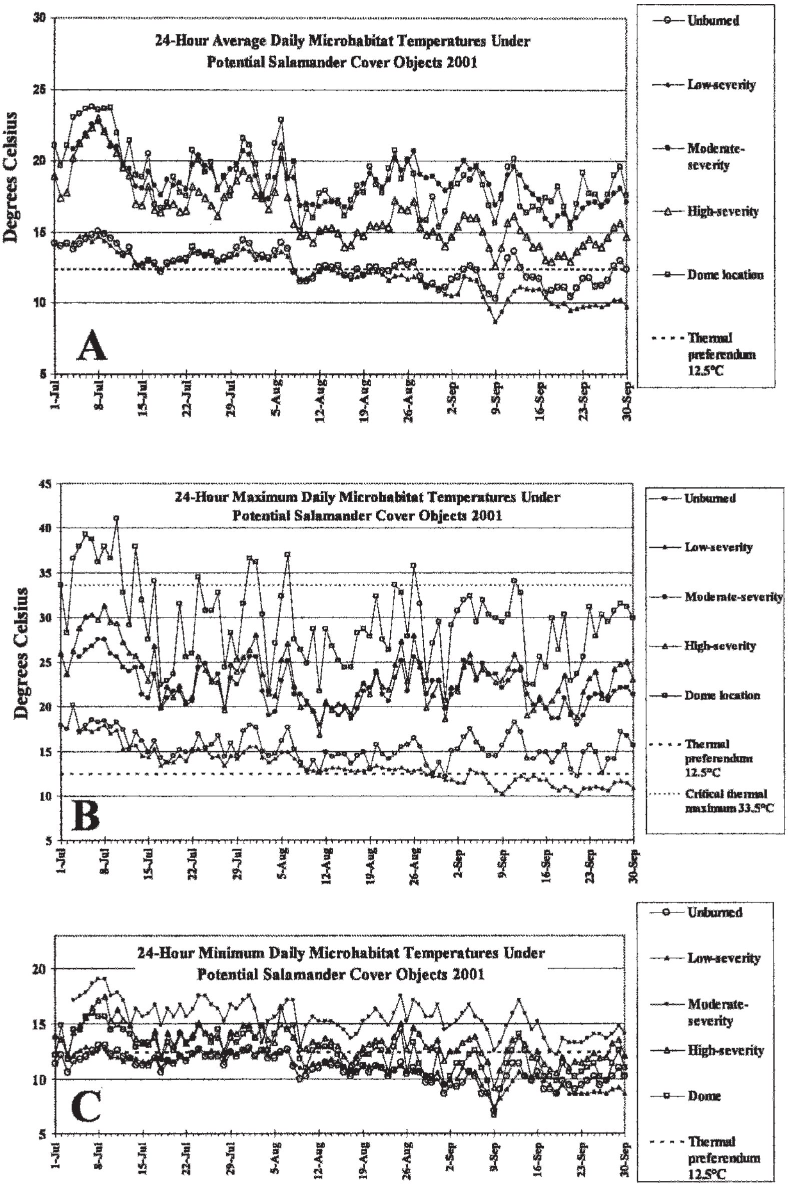

FIG. 1—Assemblages of daily microhabitat temperatures under potential cover objects for *Plethodon neomexicanus* (2001) by burn-severity type (defined in text) during period of salamander surface activity. All areas were burned in the 2000 Cerro Grande Fire, with the exception of the Dome location, which burned with high-severity in the 1996 Dome Fire. The reported microhabitat thermal preferendum for *P. neomexicanus* is 12.5°C (Williams, 1972). Note that panels have different scales on the x-axis. A) Average daily microhabitat temperatures. B) Maximum daily microhabitat temperatures. C) Minimum daily microhabitat temperatures.

greater in high-severity and moderate-severity areas than in low-severity and unburned areas (Fig. 1). Temperature differences were more extreme between burn-severity types for 24-h average daily temperatures and 24-h maximum daily temperature than for minimum daily temperatures (Fig. 1).

The 24-h average, minimum, and maximum daily temperatures of microhabitats in unburned and low-severity areas fluctuated near the ther-

TABLE 2—Summary of 2000 and 2001 Time Constrained Survey (TCS) results for *Plethodon neomexicanus* at historical locations by 4 burn-severity types (defined in text) following the 2000 Cerro Grande Fire in New Mexico. The Dome location was burned in the 1996 Dome Fire, with a mosaic pattern of moderate and high severities. Average = average number of salamanders during TCS. Rate of capture = total number of salamanders/total time.

| | Number of TCSs with salamanders | | | |
|---|---|---|---|---|
| Burn severity type | Present | Absent | Average | Rate of capture |
| 2000 | | | | |
| Unburned | 5 (83%) | 1 (17%) | 2.4 | 1.0 |
| Low | 1 (20%) | 4 (80%) | 2.0 | 0.2 |
| Moderate | 2 (29%) | 5 (71%) | 2.0 | 0.3 |
| High | 5 (42%) | 7 (58%) | 7.0 | 1.5 |
| Dome location | 2 (100%) | 0 (0%) | 1.5 | 0.8 |
| 2001 | | | | |
| Unburned | 10 (36%) | 18 (64%) | 3.9 | 0.7 |
| Low | 2 (40%) | 3 (60%) | 1.5 | 0.3 |
| Moderate | 2 (50%) | 2 (50%) | 1.5 | 0.4 |
| High | 4 (27%) | 11 (74%) | 7.0 | 0.9 |
| Dome location | 2 (100%) | 0 (0%) | 1.5 | 0.8 |

mal preferendum for *P. neomexicanus*; in moderate-severity and high-severity areas, and at the Dome location, only the 24-h minimum daily temperatures had some overlap with the thermal preferendum (Fig. 1). No significant difference was detected between the 24-h average daily microhabitat temperature in unburned areas and the thermal preferendum ($P = 0.521$). The 24-h average daily microhabitat temperatures in areas burned with low-severity were significantly lower than the thermal preferendum ($P = 0.007$) and were significantly greater in areas burned with moderate-severity ($P < 0.001$) and high-severity ($P < 0.001$), as well as at the Dome location ($P < 0.001$). There were some occasions during the period of salamander surface activity in areas burned with high-severity and at the Dome location when the 24-h maximum daily temperature exceeded 33.5°C, the critical thermal maximum for this species (Whitford, 1968). It should be noted that the occasions where high-severity site temperatures exceeded the critical thermal maximum do not appear on Fig. 1B, because the graph is an average of 24-h daily maximum temperatures from all data-loggers within a burn-severity.

*Study 2*—We conducted 32, 2-person-hour TCS in 2000 and 54 in 2001 (Table 2). The percentages of presence-absence were similar for the different burn-severity types for both 2000 and 2001 (Table 2). In most cases, the percentage of surveys where salamanders were absent was greater than the percentage of surveys where salamanders were present. At sites where salamanders were present in areas burned with high-severity, there was a notably greater number of salamanders detected and greater rate of capture.

*Study 3*—The number of observed salamanders was variable at both the Dome location and the Posos location, with generally decreasing trends. Salamander size distributions shifted at the Dome location in years following the wildfire; size distributions were stable at the Posos location (Fig. 2). In 1998, there was an increase in the proportion of juvenile salamanders observed at the Dome location; in 1999 and 2000, there was a decrease in the proportion of large adults observed. We detected significant differences in the distributions of sizes of salamanders at the Dome location: 1999 was significantly different from 1992, 1994, and 1997; 2000 was significantly different from 1991, 1992, 1994, 1997, and 1998 (Fig. 2). The measure of body condition resulted in no apparent effect from the Dome Fire. Finally, we observed no trend in tail damage of salamanders at the Dome location relative to itself pre-fire and post-fire, nor relative to the Posos location (Table 3).

DISCUSSION—*Study 1*—Our data indicated that microhabitat temperatures under cover objects for *P. neomexicanus* have been greatly altered after stand-replacing fires (Dome and Cerro

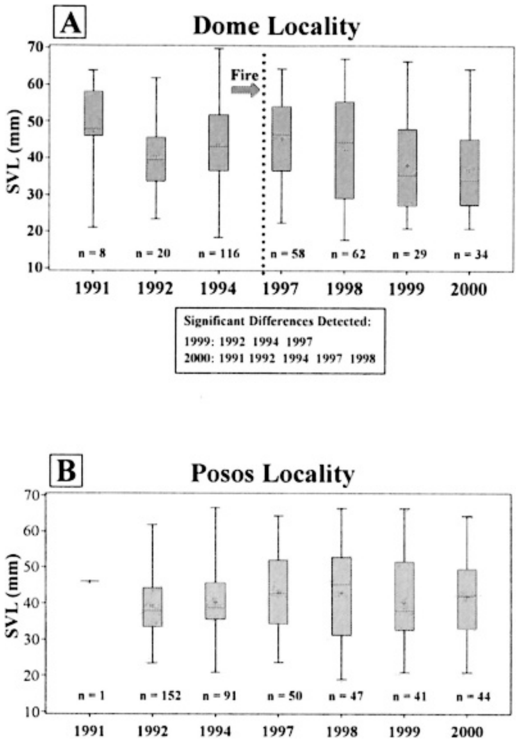

FIG. 2—Box plots of snout–vent length (SVL) of *Plethodon neomexicanus* measured at A) the Dome location burned in the 1996 Dome Fire with a mosaic pattern of moderate-severity and high-severity, and B) the Posos location, which did not burn. The bars represent 100% of the data, the shaded boxes include 50% of the data, the line is the median, and the plus (+) is the mean of the data. Statistical differences between years are called out in the box below the graph. No statistical differences between years were detected at the Posos locality.

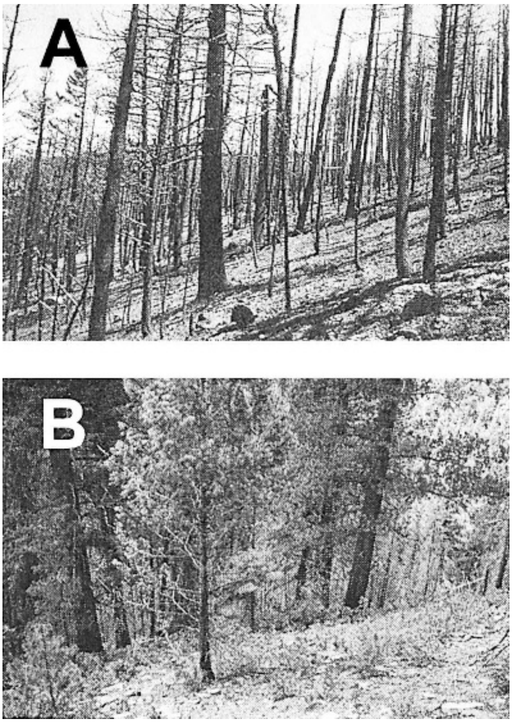

FIG. 3—Examples of *Plethodon neomexicanus* habitat in New Mexico taken in 2000: A) in an area burned with high-severity at a previously known location, and B) in an unburned area (fire-suppressed) at a previously known location.

Grande), with the most significant alterations in areas burned with moderate-severity and high-severity. While some of the observed differences in temperatures between burn-severity types are likely due to intrinsic site differences (Table 1), the temperature differences were so extreme that the intrinsic site variation is likely not a considerable factor. Furthermore, the extreme temperature differences are likely a result of different canopy cover between burn-severity types (Table 1, Fig. 3). Increased canopy cover

TABLE 3—Numbers and percentages of *Plethodon neomexicanus* with damaged and undamaged tails. The Dome location in New Mexico was burned in the 1996 Dome Fire, with a mosaic pattern of moderate and high severities. The Posos location was not burned.

| | Dome | | Posos | |
|---|---|---|---|---|
| Year | Damaged | Undamaged | Damaged | Undamaged |
| 1992 | 1 (5%) | 19 (95%) | 25 (17%) | 126 (83%) |
| 1994 | 72 (68%) | 34 (32%) | 48 (53%) | 43 (47%) |
| 1997 | 12 (33%) | 24 (67%) | 6 (52%) | 24 (48%) |
| 1998 | 17 (30%) | 39 (70%) | 25 (56%) | 20 (44%) |
| 1999 | 12 (43%) | 16 (57%) | 28 (70%) | 12 (30%) |
| 2000 | 4 (12%) | 30 (88%) | 8 (19%) | 35 (81%) |

not only decreases solar influence, but also helps retain moisture.

Microhabitat temperatures relative to the thermal preferendum for this species have been most greatly affected in areas burned with moderate-severity and high-severity. Additionally, there were some occasions in areas burned with high-severity and at the Dome location where the daily maximum temperature exceeded 33.5°C, the reported laboratory critical thermal maximum for *P. neomexicanus* (Whitford, 1968). Heatwole (1962) reported certain substrates in an oak-pine-aspen (*Quercus-Pinus-Populus*) forest in which the critical thermal maximum for *P. cinereus* was exceeded; he concluded that temperature excluded this salamander from these substrates and that the upper tolerance limit was the most important factor influencing the microdistribution of *P. cinereus* in this forest type. It is in areas burned with moderate-severity and high-severity that temperatures will have the greatest affect on terrestrial salamanders.

Although the 24-h daily average and daily maximum microhabitat temperatures in areas burned with moderate-severity and high-severity and at the Dome location exceeded temperatures found in low-severity and unburned areas, the thermal preferendum, and in some cases, the critical thermal maximum, there were times where minimum temperatures in these moderate-severity and high-severity areas were at or near the thermal preferendum. Because there were times within a 24-h period when temperatures fall to or near the thermal preferendum, this suggests that it is still possible for salamanders to be active at their preferred temperatures. However, this might require behavioral adjustments. Indeed, salamanders might be behaviorally adjusting to the altered surface habitat, such as moisture, temperature, and lack of available cover objects. We observed 9 salamanders clumped under a single, mostly burned log, and 3 salamanders under an adjacent rock on a slope burned with high-severity in 2000; the log was the only remaining log on the slope and there were few rocks at the surface. The 12 salamanders were the only salamanders found on that slope during 2-person-hours of surveying. Occasionally, 2 *P. neomexicanus* individuals can be found under a single cover object, but reports of *P. neomexicanus* since the 1980s have never recorded clumping of salamanders to such an extent. This observed salamander clumping is an example of how they might be modifying their behavior post-fire. Furthermore, salamanders might adjust the timing of their surface activity, become more or less aggressive over the available cover, or increase dispersion looking for more suitable habitat. Increased temperatures also would likely change physiological responses in salamanders if they did not adjust behaviorally to avoid the higher temperatures. Williams (1972) reported that in *P. neomexicanus*, oxygen consumption increased at higher temperatures, and Spotila (1972) reported that temperature had a direct effect on rehydration rates in other plethodontid salamanders, and in most instances, dehydration rates were greater than rehydration rates. Although we do not know the actual effect of increased microhabitat temperature, the increased temperatures might be impacting salamanders in multiple ways.

*Study 2*—Hyde and Simons (2001) reported numerous ways in which underlying assumptions for comparison of salamander count data can be violated, including differences in quality of habitat characteristics, such as ground cover, soil moisture, and soil temperature. Additionally, Schmidt (2003) detailed the problem of comparing amphibian count data that have not been adjusted for detection probabilities. He demonstrated why different habitats have different probabilities of detecting amphibians and bias the data if not adjusted. In our study, if we were to assume equal detection probabilities and test numbers of salamanders encountered, we would find no significant differences. Additionally, there was a greater rate of capture in high-severity areas. We observed that the simplified habitat that remained in areas burned with high-severity made detection of salamanders easier than that in the complex habitat in unburned areas (Fig. 3), and our previous example of salamanders clumping (Study 1) further supports this observation. Overall, these data support how unadjusted data for salamander counts could be biased because of environmental conditions and could potentially lead to misinterpretation. Because we did not account for detection probability, we present these data to demonstrate the importance of incorporating detection probabilities in comparisons of salamander count data, and the possible misinterpretation of the data if detection probabilities are not incorporated. Furthermore, adjusted count data are still limited to indicating changes or fluctuations in the relative numbers of individuals in the population. Adjusted relative abundance data are not able to provide information regarding stability (i.e., recruitment) or health (i.e., body condition of individuals) of the populations.

Our presence-absence data indicated that some populations of *P. neomexicanus* persisted in the short-term after wildfire, and continued detection in burned areas was similar to continued detection in unburned areas (Table 2). Presence-absence data are important after drastic habitat alterations because they allow quick assessment of the persistence of populations, provided that there is confidence that an absence is a true absence. Confidence in true absences can be increased through repeated surveys at the same site within the same year, as well as for repeated years. Presence-absence data might have some applications regarding monitoring a species range-wide over an extended period of time, but cannot be used to measure effect of a disturbance (unless the disturbance eliminated a significant proportion of the populations) or to monitor individuals of a population. To measure effects of disturbance within populations, other techniques should be employed (see Conclusions).

*Study 3*—Hairston (1987) reported that in many species of salamanders, particularly in long-lived species, the immature stages are more sensitive to disturbance than are adults. In our case, we expected to observe either stability in size distribution or a decrease in the number of small juvenile and sub-adult salamanders. Our results were not as expected.

Salamanders are ectothermic and use their environment to regulate body temperature and metabolic processes. Plethodontid salamanders are also known to be especially sensitive to moisture levels, pH, and temperature (Rome et al., 1991; Shoemaker et al., 1991; Petranka, 1998). Furthermore, plethodontid salamanders of different sizes often prey upon food items of different sizes: larger individuals eat larger prey and smaller individuals eat smaller prey (Camp and Bozeman, 1981; Harestad and Stelmock, 1983; Lynch, 1985; Whitaker et al., 1986). These factors have the potential to affect salamanders of different sizes in different ways. Our observation of fewer large *P. neomexicanus* might be because, in comparison to juvenile salamanders, adults are: 1) differentially responding to altered conditions by not surfacing during inhospitable conditions (resulting in biased sampling), 2) leaving the area to search for preferential habitat or food, 3) differentially stressed to the extent of increased mortality, or 4) experiencing a differential rate of predation.

We know from our mark-recapture efforts that we only observed a portion of the population of *P. neomexicanus* at any one time. It is possible that we have a biased sample resulting from adult salamanders not surfacing from underground retreats in 1999 and 2000. Adult salamanders might not have the same requirements to come to the surface as juveniles and sub-adults, i.e., spending less time at the surface (presumably to feed) if they have greater energetic reserves to draw upon. However, if factors at the Dome location limited adult salamander surface activity, we would have expected to observe a decrease in 1996 to 1998 and 1999 to 2000. Furthermore, we did not consider biased sampling in 1999 to 2000 attributable to climatic factors, because we observed stable size distributions at the Posos location. Neither did we consider the influence of local weather to be important, because we only conducted surveys when surface conditions were locally wet. While the decreasing trend in number of observed salamanders might influence the size distribution of observed salamanders, we suggest that this is not the case, because the size distribution at the Posos location was stable and also had a decreasing trend in the number of salamanders observed.

Many studies have demonstrated behavioral and physiological responses in salamanders to temperature, moisture, and pH (Heatwole, 1962; Whitford, 1968; Spotila, 1972; Keen, 1984; Frisbie and Wyman, 1991, 1992; Sugalski and Claussen, 1997). It seems unlikely, however, that environmental variables such as temperature, moisture, and pH alone would cause the observed shift in size distributions. We expected these variables would either affect salamanders of all sizes or just small salamanders because, relative to body size, smaller salamanders have greater surface area and would more likely be affected (Hairston, 1987). However, much remains unknown regarding synergistic factors, such as environmental stressors in combination with disease. Disease alone or with additional environmental stressors could differentially affect salamanders of different ages at a specific site and not another. Additionally, altered environmental variables might be a driving force behind dispersal of large salamanders. A shift in prey availability resulting from wildfire could also potentially drive dispersal of large salamanders. Other studies have shown that some salamanders adjust foraging behaviors relative to food availability (Anthony et al., 1992; Jaeger et al., 1995; Kerby and Kats, 1998). However, differential dispersion driven by prey seems unlikely, because the greater mass of adult *P. neomexicanus* would likely provide an advantage in surviving unfavorable periods without food compared to juveniles, as reported for *Batrachoseps attenuatus* (Maiorana, 1977). Thus, adult salamanders would be less likely than juveniles to disperse in search of food, even if there was a decreased availability. Finally, the observation of fewer large salamanders could be attributed to increased predation. With little to no vegetation or woody debris, large foraging salamanders might be at greater risk of predation. However, similar rates of damage to salamander tails on our study plots did not support an increased predation hypothesis.

The above hypotheses are feasible and have the potential to explain a decrease in observed adult salamanders. However, none explain the increased number of small salamanders observed in 1998 to 2000 and, thus, could only partially explain the overall turnover in salamander size distributions. The final hypothesis for explaining the distribution of salamander sizes is that 1998 was a highly successful reproductive year induced by consecutive stressful years (1996, 1997). In subsequent years, any of the other hypotheses might explain the decrease of large salamanders.

We observed no significant changes in the measure of body condition at either location studied. These data suggest that in the short-term, for salamanders present (mostly juveniles), there was sufficient food available and conditions were not harsh enough to cause measurable desiccation following wildfire. It should be noted, however, that our measurements might not have been precise enough to detect change (i.e., from a spring scale). Future studies using body condition should use a high-accuracy scale, remove and measure food items (stomach flushing) and urine from salamanders, and record mass to the nearest 0.01 g for more accurate assessments.

*Conclusions*—The results from our 3 studies suggest that novel stand-replacing wildfires in the Jemez Mountains are impacting populations of *P. neomexicanus*. We support the use of surveys to detect presence-absence of salamanders immediately following a disturbance, but presence-absence surveys should not be relied upon solely to monitor a species after disturbance. Surveys have the potential to be more useful to monitor a species if detection probabilities are determined and relative abundance data are used. However, using adjusted relative abundance data still only indicates changes in numbers of salamanders and not the stability or health of disturbed populations. Using salamander size distribution and body condition data offer mechanisms to monitor changes within a population that could more accurately monitor population stability or health after disturbance. Further, measurement of environmental parameters that are known to be important to salamanders can help us understand how populations are affected by disturbance. We suggest that by monitoring aspects of disturbed populations, such as size distributions, body condition, and environmental parameters, and comparing them to undisturbed populations, we might be able to more closely monitor the effect of the disturbance on the population, as well as better understand what is causing the effects such that we can make informed management decisions.

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