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201 pages.

Does the Sacramento Mountain Salamander Require Old-Growth Forests?[1]

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Studies of populations of *Aneides hardii* before and after logging disturbance of their mixed-conifer habitat showed no detectable short-term (0.5-3.5 years) effect. The distribution of salamanders among size classes differed on logged and unlogged sites in 1989, but the result may be due to sampling error. Although *Aneides hardii* populations persist through the first intensive cutting, they may not survive the repeated 10-year logging cycle that is planned by the U.S. Forest Service. More frequent cutting may destroy the present subterranean habitat structure which is probably vital to the salamander's survival.

INTRODUCTION

Woodland salamanders are a diverse tribe (Plethodontini, "plethodonines") of lungless salamanders (Plethodontidae) that are characterized by a complete suppression of the larval stage; eggs are laid in terrestrial nests and the hatchlings look like miniature adults (Wake 1966). Being freed from the necessity of breeding in bodies of water, plethodonines have colonized moist forest litter habitats throughout the United States.

Many plethodonine species are small, isolated fragments of former, more widespread distributions (Wake 1966). This fact, combined with their low vagility and susceptibility to heat and desiccation, make the continued existence of many species especially vulnerable to habitat changes, whether they result from long-term climatic trends or from alterations by humans and their agents.

Previous studies of terrestrial salamanders in disturbed areas have concentrated on the effects of logging and fire, which are probably the most pervasive human-mediated disturbances at the present. The majority of these studies were done in the Pacific Northwest, and many of the results were presented in two symposia (Ruggiero et al. 1991, Szaro et al. 1988). Other studies were carried out in Virginia, Alabama, North Carolina, and New York (Ash 1988, Blymyer and McGinnes 1977, Dodd 1991, Petranka et al., in press, Pough et al. 1987). These studies are correlational, i.e., the researchers compared the numbers of salamanders or burrows observed on forest lands that were in different stages of recovery from disturbance.

We feel that the reliability and generality of the detailed conclusions reached in most or all of these studies suffer from two important drawbacks. One is the bias introduced by sampling methods. All of the studies cited above, except that of burrow counting, depend on the detection of salamanders on or near the surface. Plethodonines are fossorial and an unknown percentage of the population is on the surface at any one time (Dodd 1990). The assumption that this percentage is the same in distinct sampling environments is probably wrong. Because of the unknown effects of this factor, it is probably misleading to compare directly the numbers of salamanders sampled in logged and unlogged habitats. The most reliable conclusions are drawn where species are ubiquitous and abundant in mature forests but absent from areas that have been recently cleared. Such is the case for *Plethodon yonahlossee* in North Carolina (Petranka et al., in press).

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One study has overcome the drawback of unknown population sizes. Using a mark-recapture technique to estimate populations, Ash (1988) succeeded in marking about 80% of the salamanders on forested and clearcut plots during the first, second, and fourth summers after cutting. He clearly documented the disappearance of *P. jordani* from the cut plots.

The second drawback present in all previous studies stems from the fact that plethodonine salamander populations are often patchy, even in relatively uniform habitats (pers. obs.). If no prelogging studies are done, the absence of salamanders on a disturbed plot can be interpreted in three ways: the sampling is inadequate, they were eliminated by the disturbance, or they were not there in the first place. In this study, we examined plots before and after logging in an experimental approach that evaluated the effects of logging on the Sacramento Mountain salamander, *Aneides hardii*.

The Sacramento Mountain salamander is restricted to three disjunct areas of the high mountains of southcentral New Mexico (Wake 1965). The northernmost population is found in the Capitan Mountains of Lincoln County. Towards the southwest, two other populations inhabit the Sacramento Mountains; one is centered on Sierra Blanca Peak, Lincoln County, in the central part of the mountain chain, and the other occurs from Cloudcroft, Otero County, southward to the southern end of the mountain range. Salamanders are found from about 2,400 m to the top of Sierra Blanca Peak (3,570 m; Moir and Smith 1970). Most of the salamander's mixed-conifer forest habitat occurs within the Lincoln National Forest, with small amounts on the Mescalero Apache Indian Reservation and on private lands. The distribution is a fragmented relict of one that was continuous in cooler and moister periods during the Pleistocene (Lowe 1950, Murray 1957, Pope and Highton 1980).

Although much of the range of *A. hardii* has been subject to logging for about 100 years, the Forest Service has recently adopted a plan that will increase the intensity and geographic scope of logging beyond historic levels (U.S. Forest Service 1986a). During the current 10-year plan, logging will only take place within the range of the southernmost population enclave of the salamander (U.S. Forest Service 1986b), but future plans may include logging of the Sierra Blanca and Capitan Mountains habitats.

Logging is the primary threat to the Red Hills salamander, *Phaeognathus hubrichti*, one of six plethodontid species on the U.S. List of Threatened and Endangered Species (Dodd 1991, Greenwalt 1976, U.S. Fish and Wildlife Service 1991), and timber harvest is implicated in the declines of many of the 29 other species of woodland salamanders, including *A. hardii*, that are either under review or proposed for listing by the U.S. Fish and Wildlife Service (Drewry 1991, Jacobs 1988). *Aneides hardii* is currently listed as endangered by the New Mexico Department of Game and Fish.

In response to the expressed concerns of environmentalists and government agencies, the Lincoln National Forest funded a series of studies designed to measure the impact of logging on populations of the Sacramento Mountain salamander. The research described here was a part of these studies.

DESCRIPTION OF THE HABITAT

The mixed-conifer forest inhabited by *A. hardii* is found above 2,400 m. Selective and clearcut logging has been extensive during the last 100 years on slopes less than 40%, but the study areas were all mature forests with some characteristics of old-growth (downed logs, snags, large trees). Dominant overstory species include white fir (*Abies concolor*) and Douglas-fir (*Pseudotsuga taxifolia*) with lesser amounts of Engelmann spruce (*Picea engelmanni*) and southwestern white pine (*Pinus strobiformis*). Rocky Mountain maple (*Acer glabrum*), gooseberry (*Ribes* spp.), and oceanspray (*Holodiscus dumosus*) share the open understory with seedling conifers and downed logs in various stages of decay.

Prior to the present logging cycle, ground cover was predominantly litter (conifer needles and twigs) in all sites except one, where the dominant cover was loose rocks. Herbs, woody debris (branches, logs, and bark), and moss were other common components of the ground cover. Limestone rocks and boulders are exposed on the slopes.

Ramotnik and Scott (1988) showed by multivariate analysis that the salamander was more common in areas at higher elevations with Engelmann spruce, large white fir and Douglas-fir trees, and large downed logs. Salamander presence was negatively correlated with the presence of white and ponderosa pine (*Pinus ponderosa*). Salamander populations were ubiquitous above 2,800 m, but they were scarce and patchy at lower elevations.

METHODS

Between 1986 and 1990, we sampled 21 sites inhabited by salamanders in mature mixed-conifer forest on or near four timber sales in the Lincoln National Forest, Otero County, New Mexico (2,700-2,900 m elevation). Sixteen of the sites were experimental and scheduled to be logged, and five sites served as unlogged controls. At an arbitrary spot near the center of each site on a 20 by 50 m plot, we recorded the species and diameters of the trunks of trees greater than 2 m tall. We measured ground cover, woody debris, percent slope, aspect, and canopy cover on a 2 by 50 m plot that bisected the larger plot parallel to the slope. Five sites were established in 1986, seven more were added in 1987, four in 1988, and five in 1989.

Almost half of the sites had a northern aspect (315°-45°), but aspects of the other sites included all of the remaining cardinal points. Slopes varied from level to 70%, but most were between 25% and 40%. Canopy cover was 50% to 91%.

Salamander populations were assessed during wet weather by time-constrained searches (TCS; Bury and Raphael 1983, Campbell and Christman 1982, Corn and Bury 1990, Raphael and Rosenberg 1983) in the immediate vicinity of the vegetation sites. Searches were 1 person-hour in duration in 1986 and 2 person-hour thereafter. During the searches, one to four workers turned cover objects and tore apart rotted logs. Salamanders were counted and usually measured from the tip of the snout to the posterior margin of the vent. All sites were not surveyed each year. In order to evaluate the technique, TCS were repeated two to four times on 18 unlogged sites, nine of which were sites not associated with this logging study.

Two sites were logged between the 1986 and 1987 salamander activity seasons, six were logged between the 1987 and 1988 seasons, one plot was logged before the 1989 season, and seven sites were logged before the 1990 season. Logging methods and intensity varied among the sites, but the final result was a very open woodland where sunshine penetrated to the surface litter (fig. 1). Slash was either left in place or piled. Three of the sites (BR 1-3) were logged by cable and the other 13 were tractor logged. Salamander populations were evaluated again by TCS after logging.

The results of TCS are very dependent on the sampling environment (Corn and Bury 1990). The unlogged forests that we sampled are structurally very similar, but the habitat is very different after they are logged. For this reason, it is unrealistic to compare directly the number of salamanders in unlogged and logged sites. However, long-term trends can probably be detected by repeated TCS sampling in the same habitat through several years.

Salamanders are long-lived, and populations could persist for many years even though reproduction may be inadequate to permanently maintain the population (Hairston 1987). Therefore, the success or failure of reproduction and juvenile survival may be one of the first clues to the future trajectory of the population. We studied the size class distributions of salamanders in the 1990 samples for insight into the question. Sixteen logged and five unlogged sites were compared by the Chi-square test (Siegel 1956). Differences in sample distributions were considered significant when $P < 0.05$.

Figure 1.--Mixed conifer forest plots before (above) and after (below) tractor logging, Lincoln National Forest, Otero County, New Mexico. The logged forest is a result of the least intensive type of logging practiced in this area.

RESULTS

Counts of the number of salamanders in repeated TCS on the same unlogged sites differed by as much as a factor of almost 6, but differences were usually less than 50% (table 1). The use of the TCS technique before and after logging yielded results that are reliable enough to evaluate the immediate question of whether or not *Aneides* populations survived through the actual logging process. However, because of their variability, TCS results must be used conservatively, and long-term population trends can only be detected in samples repeated over several years.

Aneides hardii was present in our samples on all sites except one before and after logging (table 2). In 1990, two sites had been cut for 3.5 years, six had been cut for 2.5 years, one had been cut for about 1.5 years, and seven had been cut for about 6 months.

The distribution of size classes of salamanders in logged and unlogged sites differed in 1990 ($P < 0.01$, fig. 2).

DISCUSSION

Time-constrained searches are subject to biases that are not usually explicitly recognized by workers who use them (Aubry et al. 1988, Bury 1983, Ramotnik and Scott 1988, Raphael 1984, 1988, Raphael and Barrett 1984, Welsh 1987, Welsh and Lind 1988, 1991) although Bury and Corn (1988) and Corn and Bury (1990) discussed some of the problems, and Bury and Raphael (1983) and Raphael and Rosenberg (1983) compared the efficiency of TCS with other sampling techniques.

There are several possible sources of bias and inconsistency in TCS. Salamanders move both horizontally and vertically in the soil column, depending on the weather and the season (Fraser 1976, Heatwole 1962 and references therein, Jaeger 1979, 1980). Different sexes and ages migrate differently. For instance, we observed that brooding *Aneides* females stay with their nests, resulting in fewer adult females on the surface during most of the summer. Salamanders are differentially vulnerable to TCS in different habitats.

Table 1.--Validation of the time-constrained search (TCS) method for *Aneides hardii*, Lincoln National Forest, Otero County, New Mexico. Numbers are salamanders found during TCS for 1 person-hour (1986) or 2 person-hour (1987-1990). All sites were unlogged and some were searched twice in 1 year. All searches were between 1 June and 1 September, and unusually dry periods were avoided. Dashed lines indicate that searches were not conducted.

		Year				
Site no.	Median	1986	1987	1988	1989	1990
BR 6	9.5	--	9	10	20	7
BR 7	35	--	10	28	41	57
TU 4	28	--	31	25	--	--
TU 5	88	--	--	38	88	92
SS 1	--	--	23-22	--	--	--
T 2	--	0	0	--	--	--
T 3	--	0	0-2	--	--	--
T 10	--	0	0	--	--	--
T 20	--	0	0-0	--	--	--
T 21	--	0	0-0	--	--	--
T 30	--	0	0	--	--	--
T 45	--	0	0-0	--	--	--
HA 1	36	--	--	31	41	--
HA 2	27	--	--	24	29	--
HA 3	36	--	--	36	43	17
HA 4	39	--	33	--	44	--
MO 4	2.5	--	--	--	3	2
SA 4	12	--	7	--	--	17

Table 2.--Numbers of *Aneides hardii* found on permanent study sites before and after logging, Lincoln National Forest, Otero County, New Mexico. LC indicates when the site was cable logged, and LT indicates when the site was tractor logged. Dashed lines indicate that searches were not conducted. Numbers of salamanders found before and after logging should not be compared because of differing search environments.

	Year								
Site no.	1986		1987		1988		1989		1990
BR 1	20*		--	LC	9		19		16
BR 2	26*		--	LC	15		15		8
BR 3	52*		--	LC	41		31		23
BR 4	13*	LT	14		15		34		57
BR 5	8*	LT	6		24		34		12
BR 6 (control)	--		9		10		20		7
BR 7 (control)	--		10		28		41		55
TU 1	--		14	LT	20		19		41
TU 2	--		28	LT	14		23		34
TU 3	--		10	LT	9		24		8
TU 4	--		31		25	LT	34		20
TU 5 (control)	--		--		38		88		92
HA 1	--		--		31		41	LT	12
HA 2	--		--		24		29	LT	6
HA 3 (control)	--		--		36		43		17
HA 4	--		33		--		44	LT	15
HA 5	--		--		--		49	LT	27
MO 1	--		--		--		0	LT	0
MO 2	--		--		--		5	LT	1
MO 3	--		--		--		9	LT	1
MO 4 (control)	--		--		--		3		2

* Number of salamanders extrapolated to 2-hour equivalent based on a 1-hour search.

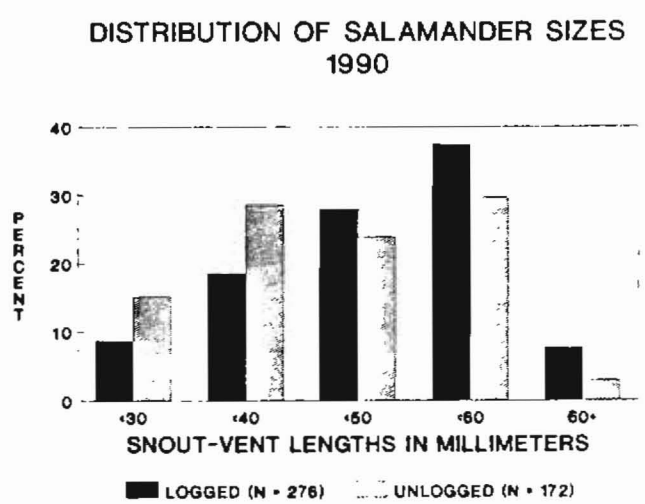

Figure 2.--Distribution among size classes of *Aneides hardii* in samples from logged and unlogged sites in 1990, Lincoln National Forest, Otero County, New Mexico. Salamanders were collected from 16 logged sites and 5 unlogged sites. Differences are significant ($\chi^2 = 15.2$, 4 d.f., $P < 0.01$).

Aneides is most often found in forested areas with deep surface litter and many large decayed logs; during dry weather salamanders can still be found in the hearts of moist rotted logs. However, salamanders also occur on sparsely vegetated rocky slopes, where they are abundant under rocks in damp weather, but they disappear entirely during extended dry spells.

Another problem that TCS shares with other sampling methods is that we have very little idea about the relation between the numbers sampled and actual population density. This is especially serious when making comparisons between species that might be expected to be differentially vulnerable to sampling (Welsh and Lind 1988). The solution to this problem requires a large number of species-specific mark-recapture studies, such as those carried out by Hairston (1987) and Ash (1988).

The destructiveness of TCS is a drawback to its use in some studies. Where space is limited, repeated TCS would rapidly modify or destroy much of the surface structure. In these cases, a less destructive method such as nighttime lantern searches is needed (Gordon et al. 1962, Pough et al. 1987), although *A. hardii* does not seem to be active in large numbers on the surface at night (pers. obs.).

There are no clear trends in the numbers of salamanders taken on either the experimental or the control sites (table 3). Although searches in the logged sites consistently yielded fewer salamanders than in the unlogged sites, the discrepancy could be simply a consequence of differing search conditions and not necessarily a reflection of differences in total salamander numbers.

Table 3.--Trends in salamander abundance in time-constrained searches, Lincoln National Forest, Otero County, New Mexico. Numbers of salamanders taken on logged and unlogged sites should not be compared because of differing search environments.

	1986	1987	1988	1989	1990
UNLOGGED SITES					
Number of searches	5	7	7	12	5
Salamanders/search	23.8	19.3	27.4	31.0	34.6
LOGGED SITES					
Number of searches	--	2	8	9	16
Salamanders/search	--	10.0	18.4	25.9	17.6

The significant difference between the size distributions of salamanders on the control and experimental sites in the 1990 surveys is perhaps indicative of incipient long-term population trends, although it may be merely a sampling artifact. With respect to the control sites, the logged sites had relatively fewer juvenile salamanders (<40 mm snout-vent length, SVL) and more adults (SVL >50 mm; fig. 2). If this pattern continues, it may signify reduced reproduction or survivorship among young salamanders in logged sites.

Removal of canopy cover can increase insolation, ground temperatures, and evaporative water loss (Geiger 1971). Diurnal, and probably annual, fluctuations are also greater after deforestation (Blymyer and McGinnes 1977, Bury 1983), and heavy machinery compacts the soil which may destroy subterranean passages (Buhlmann et al. 1988, Scott, pers. obs.). The important observation is that *Aneides* populations have survived these disturbances, at least for the short term.

Long-term survival is another question. It is still too early to determine if the *Aneides* in logged areas are reproducing at a rate that will sustain the populations, or if they will slowly disappear. The present Forest Service plan calls for a 10-year cutting cycle; that is, each logging sale will be evaluated every 10 years to determine if there is a merchantable amount of timber (U.S. Forest Service 1986b). The effects of almost continuous disturbance on salamanders cannot be predicted because this type of intensive management has not been attempted before in this forest.

Salamander populations may not be so resilient to repeated perturbations at lower, warmer elevations. Ash (1988) and Petranka et al. (in press) documented the disappearance of plethodonines after logging at lower elevations in the Appalachian Mountains. *Aneides* becomes scarce near their lower elevational limits (2,400-2,700 m), populations are restricted to mesic microhabitats, and they are absent from many sites that appear to be suitable. Logging in these areas could have an entirely different effect than at higher elevations. Postlogging studies of sites now in place at lower elevations are planned to examine this question.

A key factor in *Aneides* biology is the subterranean habitat; salamanders spend about 8 months below the

soil surface. Very few egg masses have been found, indicating that the bulk of nesting takes place underground. The soil is compact and it freezes to at least 10 cm deep. Observations made in soil pits indicate that the only apparent routes to these depths are through rotted-out root channels. Under the new cutting regime, it remains to be seen if trees cut at smaller diameters can produce the large, deeply penetrating roots that allow salamanders access to subterranean nesting and hibernating chambers.

Other species of plethodontid salamanders in different types of forests, at lower elevations, and in different structural habitats will respond to forest disturbance in different ways. Generalizations about the effects of logging on plethodontid salamanders will have to wait until we know much more about how salamanders use the habitat and how this use is modified by different logging practices (F.H. Pough, in litt.).

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