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THE EFFECTS OF FOREST CLEARCUT HARVESTING AND THINNING ON TERRESTRIAL SALAMANDERS

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Abstract: We studied short-term effects of forest clearcut harvesting and thinning on species presence, abundance, and demographics of terrestrial salamanders in an area intensively managed for forest products in southwestern Washington. We used pitfall traps to sample 4 previously harvested 45—60-year-old forested areas and 4 adjacent areas

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clearcut 2--5 years previously. In a separate experiment, we conducted surveys before and after thinning on 4 control and 4 treatment sites. Western red-backed salamanders (*Plethodon vehiculum*), ensatinas (*Ensatina eschscholtzii*), northwestern salamanders (*Ambystoma gracile*), rough-skinned newts (*Taricha granulosa*), and Dunn's salamanders (*Plethodon dunni*) were captured in both forested and clearcut areas. Columbia torrent salamanders (*Rhyacotriton kezeri*) and Pacific giant salamanders (*Dicamptodon tenebrosus*) were captured only in forested areas. Capture rates of red-backed salamanders were greater in forested than clearcut areas in fall 1994 and 1995). The size class distribution of red-backed salamanders was skewed toward the smaller size classes in clearcut areas in fall 1994 but not fall 1995. Ensatina showed no difference in capture rate or size class distribution between forested and clearcut areas in fall 1994, but showed a reduced rate of capture in clearcut areas relative to forested areas in fall 1995. Gravid females were present in both clearcut and forested areas for western red-backed salamanders and ensatinas. Although species presence was unaffected by thinning, western red-backed salamander capture rates on treatment sites were reduced after thinning. Population responses of salamander species to forest management are variable, with some species declining in abundance after clearcutting and thinning.

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salamander.

Concern over timber management in North America has prompted research on the effects of silviculture on native vertebrates. Most research has focused on bird and mammal species, while other vertebrate taxa such as salamanders have received less attention. By sheer numbers and as predators of small invertebrates, salamanders play an important role in forested ecosystems. In many forests, salamanders are the most abundant vertebrates (Burton and Likens 1975, Pough et al. 1987, Bury 1988).

Physiological constraints of terrestrial salamanders may make them especially sensitive to timber harvest and associated changes in microclimate, coarse woody debris, leaf litter cover, and soil structure. As ecotherms, salamanders require relatively stable microclimatic conditions. Forest canopy, as well as understory cover (i.e., logs, leaf litter, moss, and soil column), provides a more stable microclimate than open areas (Chen et al. 1993). The generally restricted movement and dispersal capabilities of terrestrial salamanders may limit their ability to disperse to more suitable habitat, and hence contribute to any effect of forest harvest on these species (Ovaska 1988, Stebbins 1954).

Previous research on the effects of forest management on terrestrial salamanders has concentrated on clearcut harvesting. In the Pacific Northwest, most studies have documented a lower total abundance of salamanders (all species combined) in clearcut areas than adjacent forested areas (Bury 1983, Bury and Corn

1988*a*, Raphael 1988, Dupuis et al. 1995, Cole et al. 1997). In contrast, Corn and Bury (1991) documented no significant difference in total abundance of salamanders between clearcut areas and forested areas, but some species appeared more sensitive to canopy removal than others. Although not well understood, variability is probably due to a variety of factors, including differences in precipitation and temperature regimes, clearcut harvesting, and life history.

Selective harvesting techniques such as thinning and small group selection are becoming increasingly common silvicultural practices, but studies documenting the effect of these practices on salamanders are limited. Messere and Ducey (1998) reported no significant differences in northern red-backed salamander (*Plethodon cinereus*) density between gaps created by selective harvesting and adjacent deciduous forests in central New York. In Virginia, Harpole and Haas (1999) found tha relative abundance of salamanders was lower after harvest on group selection, shelterwood, and leave-tree treatments, but not on understory removal treatments. A study in New Mexico (Scott and Ramotnik 1992) found that the Sacramento Mountain salamander (*Aneides hardii*) was present on sites after thinning, without documenting conditions prior to thinning. Studies in New York (Pough et al. 1987) and Virginia (Buhlmann et al. 1988) were inconclusive, because each study included only 1 thinned site. No studies have addressed the effects of thinning on salamanders in the Pacific Northwest.

We investigated the effects of clearcut harvesting and thinning on the presence, abundance, and demographics of terrestrial salamanders in southwestern Washington. In this area, both upland and lowland forests are primarily privately owned and intensively managed. Most of the oldgrowth forest was harvested early this century, and less than 0.1% of the current land area supports oldgrowth forest. Clearcut harvesting and thinning are common practices in the second and thirdgrowth forests of this area.

STUDY AREA

Study sites were located in the northern Willapa Hills, approximately 31 km from Oakville, Washington, on land owned by Port Blakely Tree Farms and the Weyerhaueser Company. The area is hilly with elevations ranging of 90--300 m. Temperatures are mild, with winter highs around 4--7 ^{o}C and summer highs around 23--26 ^{o}C. Precipitation levels average approximately 244 cm per year. Summers are relatively dry, with only about 5% of the annual precipitation falling between June and August. Information on meteorological conditions during amphibian sampling was obtained for Oakville, Washington from records at the Western Regional Climate Center (1993-1995).

Forests in the area are in the wet part of the *Tsuga heterophylla* zone (Franklin and Dyrness 1973) and are dominated by Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*), with western red-cedar (*Thuja plicata*) and Sitka spruce (*Picea sitchensis*) also occurring in some stands. Deciduous trees include red alder (*Alnus rubra*) and bigleaf maple (*Acer macrophyllum*). Understory vegetation is dominated by sword fern (*Polystichum munitum*), deer fern (*Blechnum spicant*), salal (*Gaultheria shallon*), Oregon grape (*Berberis nervosa*), vine maple (*Acer circinatum*), huckleberry (*Vaccinium* spp.), Devil's club (*Oplopanax horridum*), wood sorrel (*Oxalis oregana*), and *Rubus* spp.

METHODS

To study the effects of clearcut harvesting we sampled 8 sites: 4 45--60-year-old forested stands and 4 areas that were harvested 2--4 years prior to study initiation. For ease of discussion, we refer to the 45--60-year-old stands as forested areas and recently harvested stands as clearcuts. Pairing of each forested area with an adjacent clearcut provided similarity in slope, aspect, and site history (prior to clearcutting). Clearcuts had all been harvested with the aid of tractor skidders and had not been burned or sprayed with herbicides. We chose sites of sufficient size to allow a minimum 40-m buffer from edge of sampling grid to habitat edge, and we chose buffer distance based on the mobility of the species being studied. The main species of interest, the western red-backed salamander and the ensatina, have limited movements (Ovaska 1988, Stebbins 1954), and a 40-m buffer increased the likelihood that most individuals surveyed were residents of the given treatment.

We selected 8 45--60-year-old forests for the thinning study and randomly selected 4 of the sites to the control group and 4 to the treatment group. Treatment sites were thinned during the course of the study. However, only 5% of 1 of the treatment sites was thinned, so this site was not included in statistical analyses.

Thinning on the other 3 treatment sites was considered to be a "low thin" (Smith 1986) and was less intensive than most commercial thinning operations. Both skidder and high-lead logging techniques were used. Over the larger stand areas, an average of 30% of stems >15 cm diameter at breast height (dbh) was removed, and basal area was reduced by an average of 16% (from 57 m^2/ha to 48 m^2/ha).

Salamander Sampling Surveys

We used pitfall trapping to survey salamanders (Bury and Corn 1988*a*), with each pitfall trap consisting of a single number 10 tin can. A tapered plastic sleeve within each trap prevented salamander escape. We buried traps so that tops were flush with the ground surface. Each site included 36 traps (6 trap x 6 trap square with 15 m between each trap). To the extent possible, we placed pitfall trapping grids ≥ 0.5 km from aquatic breeding sites of salamanders (ponds and streams).

We conducted 3 surveys on the sites used to study clearcut harvesting effects (fall 1994, spring 1995, and fall 1995) and 5 surveys on sites used to study the effects of thinning (2 pretreatment surveys: fall 1993 and spring 1994; 3 posttreatment surveys: fall 1994, spring 1995, and fall 1995). Sites were thinned during summer 1994.

A survey consisted of a 28-day period (30 days in fall 1993) where traps were left open continuously. We checked traps approximately once per week. We recorded mass, total body length, and snout-vent length (from the top of the head to the anterior of the vent) for each captured animal. For animals that died during fall

1994, spring 1995, and fall 1995 surveys, we conducted dissections to determine reproductive status and recorded the presence of yolked eggs.

Due to lack of reliable, efficient techniques available for marking plethodontid salamanders, we did not mark captured animals. To prevent recapture within a single survey period, we refrigerated captured salamanders (to induce dormancy) and returned them to their place of capture at the close of each survey period. We acknowledge that capture totals over the entirety of survey periods could be influenced by recapture by treatment interactions, however, differential recapture rate among site types was not expected.

We reported captures per 100 trapnights as our index of salamander abundance. We used snout-vent-length data to develop sizeclass distributions for each species and site. Sizeclass histograms and the presence of gravid females were used to index population demographics.

Vegetation Sampling

We measured overstory vegetation (>1 m tall), coarse woody debris, and physiographic variables (slope and aspect) on 5 plots (15 x 15 m) at each sampling site. Coarse woody debris (10 cm diameter) included 3 decay classes, a modification of 5 categories established by Maser et al. (1979) and Franklin et al. (1981). Decay class 1 included recently fallen logs with intact bark. Decay class 2 included logs in which bark was sloughing or absent and sapwood was soft. Decay class 3 included logs in which bark was absent and all wood was soft. We measured understory vegetation (<1 m tall), coarse woody debris, fine woody debris, and leaf litter depth on 9 plots (3 x 3 m) at each sampling site. We sampled vegetation on all 16 sites during spring 1994 and sampled the 4 thinned sites a second time in spring 1995. Skidder-trail maps were also generated for thinned sites. These trails served as quantitative indices of potential soil compaction that occurred on a site, as well as indices of machine impacts received by a site.

Analysis

Both fall and spring data were used to compare species presence. For capture rate comparisons, only fall data was used, because sample sizes were too low in spring for statistical analyses. Species caught in sufficient number to test for differences in capture rate and sizeclass distribution between forested areas and clearcuts, and before and after thinning, were western red-backed salamanders and ensatinas. To test for the effects of clearcut harvesting on capture rate, we compared capture rates of each species between forested areas and clearcuts using paired *t*-tests on log-transformed data (Zar 1984). To test for the effects of thinning on capture rate, we conducted a series of orthogonal contrasts with one factor being year-by-year interactions and the other factor being treatment. One contrast tested for differences between the 2 posttreatment fall surveys, and a second contrast tested the pretreatment survey period to the mean of the 2 posttreatment fall surveys. We did not analyze the 2 posttreatment fall surveys separately because they shared the pretreatment period in common and were not independent. Captures during the spring postthinning survey were insufficient to allow comparisons of capture rates.

We used *G*-tests for goodness of fit to compare sizeclass distributions of each species between forested areas and clearcuts, and before and after thinning. We compared data from the 2 postthinning surveys, and then averaged these and compared the average to the prethinning period. We used 2-factor analysis of variance with the statistical software package SPSS 7.5 to compare vegetation between forested areas and clearcuts, and before and after thinning (SPSS 1997). We used transformed data (log or arcsine transformation) when necessary (Zar 1984).

The power of capture rate comparisons was assessed using the PASS 6.0 computer program (NCSS 1996). Tests of salamander capture rate and sizeclass distribution were considered significant if $P \leq 0.05$. To maintain an overall alpha level of 0.05 for vegetation comparisons, the alpha level for each vegetation test was adjusted using Bonferonni's inequality (Piegorsch and Bailer 1997). Consequently, with 16 vegetation variables tested, the Bonferroni-corrected significance level was 0.0032 for each test.

RESULTS

Effects of Clearcut Harvesting

Effects of Clearcut Harvesting on Salamander Presence.---We captured western red-backed salamanders, ensatinas, northwestern salamanders, rough-skinned newts, and Dunn’s salamanders in both forest and clearcut areas. We captured Columbia torrent salamanders and Pacific giant salamanders in 3 of 4 forests but none of the 4 clearcut areas.

Effects of Clearcut Harvesting on Salamander Abundance.---Fall captures of red-backed salamanders were 175 and 121 in 1994 and 1995. Capture rates were greater in forested areas than clearcuts (t = 7.705, df = 3, P = 0.005 for fall 1994; t = 6.787, df = 3, P = 0.007 for fall 1995; Fig. 1). Ensatinas capture rates were similar in forested areas and clearcuts (2.04 captures per trapnight [TN] in each site type) in fall 1994 (t = 0.212, df = 3, P = 0.845). Capture rates in fall 1995 were significantly greater in forested areas than in clearcuts (t = 3.900, df = 3, P = 0.026; Fig. 1).

Effects of Clearcut Harvesting on Salamander Demographics.--- We captured gravid females in both forested areas and clearcuts for western red-backed salamanders and ensatinas. Because sizeclass distributions of each species were very similar among different sites within a site type, we combined the data to form 2 sizeclass distributions for a given species in the 4 forested areas and the 4 clearcuts. In fall 1994, there was a significant difference in sizeclass distribution between forested areas and clearcuts for red-backed salamanders (G = 12.954, df = 6, P = 0.045), with a skewing of sizeclasses in the clearcuts toward the smaller classes. In fall 1995, red-backed salamanders showed no difference in sizeclass distribution between the 2 site types (G = 2.761, df = 4, P = 0.604). We combined fall 1994 and fall 1995 data for ensatina because patterns were similar for the 2 years. Ensatinas showed no difference in sizeclass distribution between forested areas and clearcuts (G = 9.043, df = 6, P = 0.186; Fig. 2).

Vegetation in Forests and Clearcut Areas.---Forests contained greater percent cover of canopy (F = 463.0, df = 1, 35, P < 0.0001), decay class 3 coarse woody debris (F = 11.67, df = 1, 32, P = 0.0016), leaf litter (F = 33.38, df = 1, 64, P < 0.0001), and moss (F = 21.99, df = 1, 64, P < 0.0001), and greater litter depth (F = 334.7, df = 1, 64, P < 0.0001) than clearcuts (Table 1). Clearcuts contained greater percent cover of fine woody debris (F = 43.33, df = 1, 67, P < 0.0001) and grass (F = 15.30, df = 1, 64, P = 0.0002) than forested areas (Table 1).

Effects of Thinning

Effects of Thinning on Salamander Species Presence and Abundance.---There was no effect of thinning on species presence; for a given site, all species that were captured before thinning were also captured after thinning. For both control and treatment sites, capture rates of red-backed salamanders and ensatinas were greater in the 2 posttreatment fall periods (1994 and 1995) than the pretreatment fall period (1993). This increase was much more dramatic for red-backed salamanders on control sites than treatment sites, and this species showed a significant difference in relative rate of capture after thinning (t = 3.634, df = 5, P = 0.015) (Fig. 3). Variability in capture rate of ensatinas precluded a determination of the effects of thinning on the abundance of this species.

Effects of Thinning on Demographics.--- For western red-backed salamanders and ensatinas, we captured gravid females on all sites both before and after thinning . We combined fall 1994 and fall 1995 posttreatment data for comparisons of sizeclass distribution, because patterns were similar between the 2 years. For each species, comparison of the average posttreatment sizeclass distribution to the pretreatment distribution showed no change after thinning.

Effects of Thinning on Vegetation.-- Significant differences in vegetation variables were not evident after thinning (Table 1). The extent of skidder trails varied among treatment sites. Sites T1 and T4 were predominantly skidder-thinned and had the greatest extent of skidder trails. About 8% of site T1 and 15% of site T4 was covered with skidder trails. Site T2 (0% trails on site) received minimal thinning, but the area surrounding the site was skidder-thinned and contained many skidder trails. Site T3 (0% trails on site) was predominantly high-lead thinned, and contained only a short skidder trail northwest of the site.

Precipitation During Sampling Sessions.---Total precipitation in nearby Oakville, Washington during the fall 1993 sampling period was 1.7 cm, while total precipitation was 8.0 cm and 7.8 cm, respectively, for fall 1994 and 1995 survey periods (Western Regional Climate Center, 1993--1995).

DISCUSSION

Effects of Clearcut Harvesting

The presence of red-backed salamanders and ensatinas on all forested areas and clearcuts was expected because these species are the most abundant terrestrial salamanders in the region. The presence of northwestern salamanders and rough-skinned newts in clearcuts may indicate tolerance of these areas or migrational behavior. Northwestern salamanders and rough-skinned newts can migrate long distances to and from breeding sites. The presence of Dunn's salamanders in clearcuts indicates that these areas are able to support this species, at least in the short term.

The lack of Columbia torrent salamander captures in clearcuts (all 13 captures occurred in forested) supports previous published findings (Nussbaum et al. 1983, Bury and Corn 1988b, Corn and Bury 1989) and may reflect this species' intolerance to desiccation (Ray 1958). The lack of Pacific giant salamander captures in clearcuts may reflect infrequent capture of this species in general (4 individuals were captured) or sensitivity to clearcut harvesting. Corn and Bury (1991) found no difference in abundance of terrestrial Pacific giant salamanders between clearcuts and old-growth forests. Results of stream studies indicate that abundance of Pacific giant salamanders may be reduced due to logging, depending on stream gradient and other factors (Hall et al. 1978, Murphy and Hall 1981, Corn and Bury 1989).

Two species, the western red-backed salamander and ensatina, were caught in sufficient numbers to allow comparisons of their abundance and sizeclass distribution in the forested areas and clearcuts. In addition to any immediate impacts that may have occurred from clearcut harvesting (i.e., directly mortality from machine operations), the lower capture rate of red-backed salamanders in clearcuts may be due to microclimatic, ground cover, and soil structural differences. The drier summers and more extreme summer and winter temperatures in clearcuts (Chen et al. 1993) may result in greater mortality of red-backed salamanders in clearcuts compared to forested areas.

Another explanation for the lower capture rates of red-backed salamanders in the clearcuts relative to forested areas is related to ground cover differences between the 2 site types. Although clearcuts did not differ from forested areas in percent coarse woody debris cover (all decay classes combined), clearcuts did contain lower percent cover of well-decayed (decay class 3) coarse woody debris. Coarse woody debris is a major cover type used by red-backed salamanders (Leonard et al. 1993, Dupuis et al. 1995), and when well-decayed, it contains more moisture than newly fallen logs (Maser and Trappe 1984), making it especially important for western red-backed salamanders residing in clearcuts. Clearcuts contained less cover of moss and leaf litter, and a shallower leaf litter layer, than forested aeras. Studies have documented red-backed salamander use of moss and leaf litter for cover (Ovaska and Gregory 1989, Dupuis 1993, North 1993). In our study, reduction in cover of well-decayed coarse woody debris, moss, and leaf litter (and leaf litter depth) in clearcuts may have interacted with the exposed conditions to reduce their abundance. Ground cover may be more important for red-backed salamanders in clearcuts than in forested areas, because this cover provides a retreat from the warmer, drier summer conditions, as well as the colder winter conditions, in clearcuts.

Lower capture rates of red-backed salamanders in clearcuts may be related to differences in soil structure. Studies have not assessed their use of the soil column, but it is thought that they access the soil column as an escape from unfavorable surface conditions (Ovaska and Gregory 1989). Heatwole (1960) found that the northern red-backed salamander uses rodent, insect, and earthworm burrows and also burrows directly into the soil itself, when soils are not compacted. Researchers have documented the use of underground retreats by other plethodontids as well (Cunningham 1960, Maiorana 1976). In general, many salamander species appear to use the soil column as a retreat from harsh microclimatic conditions on the surface (Heatwole 1962; Fraser 1976; Jaeger 1979, 1980). Soil compaction due to timber harvesting (Steinbrenner 1955, Dyrness 1965, Sidle and Drlica 1981) may render the soil column more difficult for salamanders to access. In our study, soil compaction, as with the reduction in well-decayed coarse woody debris and leaf litter cover in the clearcut areas, may have interacted with other factors to reduce red-backed salamander abundance. Although red-backed salamanders appear to be less abundant in clearcuts, the full representation of sizeclasses and presence of gravid females in clearcuts suggest that this species is reproducing in clearcuts and that these areas are not simply sink habitats that are incapable of supporting reproducing populations.

Because sizeclass distribution was different for western red-backed salamanders between forested areas and clearcuts in fall 1994 but not fall 1995, effects of clearcutting on the sizeclass distribution are unclear. The apparent skewing of sizeclass distribution toward the smaller sizeclasses in 1994 in clearcuts may simply be an artifact of sampling or may relect greater population recruitment or reduced individual growth rate of this species in clearcuts relative to forested areas. Ensatina capture rate results were more ambiguous than those for red-backed salamanders. Ensatinas capture rates were lower in clearcuts relative to forested areas in fall 1995 but not in fall 1994. As with red-backed salamanders, the full representation of sizeclasses and presence of gravid females in clearcuts suggests that this species is reproducing in clearcuts.

Initial Effects of Thinning

Species presence was not affected by thinning. Given the limited degree of habitat alteration that occurred, this result was not surprising. As with the clearcut harvesting study, red-backed salamanders and ensatinas were caught in sufficient numbers to test for immediate effects of treatment on abundance (as indicated by capture rate) and sizeclass distribution. However, variability in ensatina capture rates precluded an analysis of the effects of thinning on the abundance of this species.

A direct comparison of captures in treatment sites in fall 1993 (pretreatment) and fall 1994 or fall 1995 (posttreatment) is misleading without considering microclimatic differences between the time periods. The higher number of captures in treatment sites in fall 1994 and fall 1995 relative to fall 1993 is probably due to the higher precipitation levels, and hence increased surface activity, in fall 1994 and fall 1995. Relative comparisons of capture rates between control and treatment sites revealed that red-backed salamanders were influenced by forest thinning. The difference in relative capture rate of red-backed salamanders was somewhat surprising, because the thinning treatment was minor. The observed decline in red-backed salamanders may be explained by direct machine impacts and soil compaction from skidders. Site T3, which had no skidder trails within the site and few trails in the surrounding area, did not exhibit an effect of thinning on red-backed salamander populations. Sites T1 and T4, which had trails nearby and on site, and T2, which had no trails on site but many trails in adjacent areas, showed declines in relative abundance of red-backed salamanders. Changes in sizeclass structure were unlikely to be observed, because the posttreatment time period of this study documented only immediate effects of thinning.

Management Implications

Our evidence suggests that red-backed salamanders and possibly ensatinas decline in abundance due to clearcut harvesting. However, both species are probably breeding in clearcut areas and may recover to preharvest abundance before the next harvest (approximately 50--55 years). The infrequent capture of other species made it difficult to determine their responses to clearcut harvesting, but it appears that Columbia torrent salamanders are found almost exclusively in forested areas. Given the limited mobility of this species, Columbia torrent salamanders may be in decline on landscapes where clearcut harvesting is conducted on a large scale and where protection of riparian habitat is inadequate.

Light thinning, as done on these study sites, may cause a short-term decline in the abundance of some salamander species. After initial declines in abundance due to thinning, populations may increase in abundance, as establishment and growth of understory vegetation accelerates after thinning.

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LITERATURE CITED

Buhlmann, K. A., C. A. Pague, J. C. Mitchell, and R. B. Glasgow. 1988. Forestry operations and terrestrial salamanders: techniques in a study of the Cow Knob salamander, *Plethodon punctatus*. Pages 38-44 *in* R. C. Szaro, K. E. Severson, and D. R. Patton, technical coordinators. Management of amphibians, reptiles, and small mammals in North America. U.S. Forest Service General Technical Report RM-GTR-166.

Burton, T. M., and G. E. Likens. 1975. Salamander populations and biomass in the Hubbard Brook experimental forest, New Hampshire. Copeia 1975:541-546.

Bury, R. B. 1983. Differences in amphibian populations in logged and old-growth redwood forest. Northwest Science 57(3): 167-178.

_____. 1988. Habitat relationships and ecological importance of amphibians and reptiles. Pages 61-76 *in* K. J. Raedeke, editor. Streamside management:

riparian wildlife and forestry interactions. Contribution 59 of the Institute of Forest Resources, University of Washington, Seattle, Washington, USA.

_____, and P. S. Corn. 1988*a*. Douglas-fir forests in the Oregon and Washington Cascades: relation of the herpetofauna to stand age and moisture. Pages 11-22 *in* R. C. Szaro, K. E. Severson, and D. R. Patton, technical coordinators. Management of amphibians, reptiles, and small mammals in North America. U.S. Forest Service General Technical Report RM-GTR-166.

_____, and _____. 1988*b*. Responses of aquatic and streamside amphibians to timber harvest: a review. Pages 165-182 *in* K. J. Raedeke, editor. Streamside management: riparian wildlife and forestry interactions. Contribution 59 of the Institute of Forest Resources, University of Washington, Seattle, Washington, USA.

Chen, J., J. F. Franklin, and T. A. Spies. 1993. Contrasting microclimates among clearcut, edge, and interior of old-growth Douglas-fir forest. Agricultural and Forest Meteorology 63:219-237.

Cole, E. D., W. C. McComb, M. Newton, C. L. Chambers, and J. P. Leeming. 1997. Response of amphibians to clearcutting, burning, and glyphosate application in the Oregon Coast Range. Journal of Wildlife Management 61:656-664.

Corn, P. S., and R. B. Bury. 1989. Logging in western Oregon responses of headwater habitats and stream amphibians. Forest Ecology and Management 29:39-57.

_____, and _____. 1991. Terrestrial amphibian communities in the Oregon Coast Range. Pages 305-317 *in* L. F. Ruggiero, K. B. Aubry, A. B. Carey, and M. H. Huff, technical coordinators. Wildlife and vegetation of unmanaged Douglas-fir forests. U.S. Forest Service General Technical Report PNW-GTR-285.

Cunningham, J. D. 1960. Aspects of the ecology of the Pacific slender salamander, *Batrochoseps pacificus*, in southern California. Ecology 41:88-99.

Dupuis, L. A. 1993. The status and distribution of terrestrial amphibians in old growth forests and managed stands. Thesis, University of British Columbia, Vancouver, British Columbia, Canada.

_____, J. M. Smith, and F. Bunnell. 1995. Relation of terrestrial-breeding amphibian abundance to tree-stand age. Conservation Biology 9:645-653.

Dyrness, C. T. 1965. Soil surface condition following tractor and high-lead logging in the Oregon Cascades. Journal of Forestry 63:272-275.

Franklin, J. F., K. Cromack, Jr., W. Denison, A. McKee, C. Maser, J. Sedell, F. Swanson, and G. Juday. 1981. Ecological characteristics of old-growth Douglas-fir forests. U.S. Forest Service General Technical Report PNW-GTR-118.

_____, and C. T. Dyrness. 1973. Natural vegetation of Oregon and Washington. Oregon State University Press, Corvallis, Oregon, USA.

Fraser, D. F. 1976. Empirical evaluation of the hypothesis of food competition in salamanders of the genus *Plethodon*. Ecology 57:459-471.

Hall, J. D., M. L. Murphy, and R. S. Aho. 1978. An improved design for assessing impacts of watershed practices on small streams. Verhandlungen der Internationalen Vereinigung fur Theoretische und Angewandte Limnologie 20:1359-1365.

Harpole, D. N., and C. A. Haas. 1999. Effects of seven silvicultural treatments on terrestrial salamanders. Forest Ecology and Management 114:349-356.

Heatwole, H. 1960. Burrowing ability and behavioral responses to desiccation of the salamander *Plethodon cinereus*. Ecology 41:661-668.

_____, 1962. Relation of substrate moisture to absorption and loss of water by the salamander *Plethodon cinereus*. Ecology 42:814-819.

Jaeger, R. G. 1979. Seasonal spatial distributions of the terrestrial salamander *Plethodon cinereus*. Herpetologica 35:90-93.

_____, 1980. Microhabitats of a terrestrial forest salamander. Copeia 1980:265-268.

Leonard, W. P., H. A. Brown, L. L. C. Jones, K. R. McAllister, and R. M. Storm. 1993. Amphibians of Washington and Oregon. Seattle Audubon Society, Seattle, Washington, USA.

Maiorana, V. C. 1976. Predation, submergent behavior, and tropical diversity. Evolutionary Theory 1:157-177.

Maser, C., R. G. Anderson, and K. Cromack, Jr. 1979. Dead and down woody material. Pages 78-95 *in* J. W. Thomas, technical editor. Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington. U.S. Forest Service Agricultural Handbook 553.

_____, and J. M. Trappe, technical editors. 1984. The Seen and the unseen world of the fallen tree. U.S. Forest Service General Technical Report PNW-164.

Messere, M. and P. K. Ducey. 1998. Forest floor distribution of northern redback salamanders, *Plethodon cinereus*, in relation to canopy gaps: first year following selective logging. Forest Ecology and Management 107:319-324.

Murphy, M. L., and J. D. Hall. 1981. Varied effects of clearcut logging on predators and their habitat in small streams of the Cascade Mountains, Oregon. Canadian Journal of Fisheries and Aquatic Sciences. 38:137-145.

NCSS Statistical Software. 1996. PASS 6.0. J. L. Hintze, Kaysville, Utah, USA.

North, M. 1993. Stand structure and truffle abundance associated with northern spotted owl habitat. Dissertation, University of Washington, Seattle, Washington, USA.

Nussbaum, R. A., E. D. Brodie, Jr., and R. H. Storm. 1983. Amphibians and reptiles of the Pacific Northwest. University of Idaho Press, Moscow, Idaho, USA.

Ovaska, K. 1988. Spacing and movements of the salamander *P. vehiculum*. Herpetologica 44:377-386.

_____, and P. T. Gregory. 1989. Population structure, growth, and reproduction in a Vancouver Island population of the salamander *P. vehiculum*. Herpetologica 45:133-143.

Piegorsch, W.W., and A.J. Bailer. 1997. Statistics for environmental biology and toxicology. First edition. Chapman & Hall, London, United Kingdom.

Pough, F. H., E. M. Smith, D. H. Rhodes, and A. Collazo. 1987. The abundance of salamanders in forest stands with different histories of disturbance. Forest Ecology and Management 20:1-9.

Raphael, M. G. 1988. Long-term trends in abundance of amphibians, reptiles, and mammals in Douglas-fir forests of northwestern California. Pages 23-31 *in* R. C. Szaro, K. E. Severson, and D. R. Patton, technical coordinators. Management of amphibians, reptiles, and small mammals in North America. U.S. Forest Service General Technical Report RM-GTR-166.

Ray, C. 1958. Vital limits and rates of desiccation in salamanders. Ecology 39:75-83.

Scott, N.J. Jr., and C.A. Ramotnik. 1992. Does the Sacramento Mountain salamander require old-growth forests? Pages 170-178 *in* M. R. Kaufmann, W. H. Moir, and R. L. Bassett, technical coordinators. Old-growth forests in the southwest and Rocky Mountain regions. U.S. Forest Service General Technical Report RM-GTR-213.

Sidle, R. C., and D. M. Drlica. 1981. Soil compaction from logging with a low-ground pressure skidder in the Oregon Coast Range. Soil Science Society of America Journal 45:1219-1224.

Smith, D. M. 1986. The Practice of Silviculture. Eighth edition. John Wiley & Sons, New York, New York, USA.

SPSS. 1997. SPSS Version 7.5. SPSS, Inc., Chicago, Illinois, USA.

Stebbins, R. C. 1954. Natural history of the salamanders of the plethodontid genus *E._eschscholtzii*. University of California Publications in Zoology 54:47-124.

Steinbrenner, E. C. 1955. The effect of repeated tractor trips on the physical properties of forest soils. Northwest Science 41:155-159.

Swan, A. V., R. J. Baker, and J. A. Nelder. 1989. The generalised linear interactive modelling system: manual. Release 3.77. Numerical Algorithms Group, Oxford, United Kingdom.

Western Regional Climate Center. 1993-1995. Oakville, Washington weather data. Reno, Nevada, USA.

Zar, J. H. 1984. Biostatistical Analysis. Second edition. Prentice Hall, Englewood Cliffs, New Jersey, USA.

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Table 1. Comparison of vegetation and ground cover characteristics between forested areas and clearcuts and before and after thinning in Douglas-fir/western hemlock forests, Washington, 1993-1995.[a]

Variable	Forested Areas		Clearcuts		Before Thinning		After Thinning	
	Mean[b]	SD	Mean[b]	SD	Mean[b]	SD	Mean[b]	SD
Canopy cover >3m (%)**	85.4	3.7	0.4	0.5	80.3	3.5	77.5	6.8
Cover of vegetation <3m (%)								
Tree saplings (1-3m)	0.7	0.6	1.3	2.2	0	0	0	0
Tree seedlings (<1m)	1.6	1.6	2.3	1.5	0	0	0	0
Shrubs	2.1	2.7	3.1	5.4	3.9	3.7	3.5	3.9
Ferns	11.0	7.9	9.7	11.7	10.4	4.8	7.6	5.7
Ground Cover (%)								
Coarse woody debris	6.6	3.9	6.3	4.0	10.2	5.2	9.7	4.1
Decay class 1 logs	0.9	0.9	1.5	0.9	0.8	0.2	2.0	0.9
Decay class 2 logs	0.9	0.5	2.1	2.2	1.5	1.4	1.2	1.1
Decay class 3 logs*	4.4	1.7	1.4	1.5	8.1	4.2	7.8	4.6
Fine woody debris**	13.1	4.9	45.3	7.5	10.0	7.9	12.2	8.3
Leaf litter**	47.8	18.4	18.0	16.4	47.8	18.4	18.0	16.4
Moss**	40.9	21.7	14.6	14.4	41.4	16.4	32.2	15.2
Forbs	4.2	4.0	13.4	9.3	0	0	0	0
Grass	0.1	0.1	9.0	9.0	0.1	0.1	0.1	0.1
Rock	0	0	0.1	0.2	0	0	0	0
Litter depth (cm)**	2.4	0.3	0.9	0.2	2.1	0.6	1.7	0.5

Table 1. Continued.

[a] after Bonferroni-adjustment, *P*-value for significance is 0.0032 for each test.

[b] ($n = 4$)

* indicates a difference at $0.0032 \geq P > 0.0001$.

** indicates a difference at $P \leq 0.0001$.

FIGURE LEGENDS

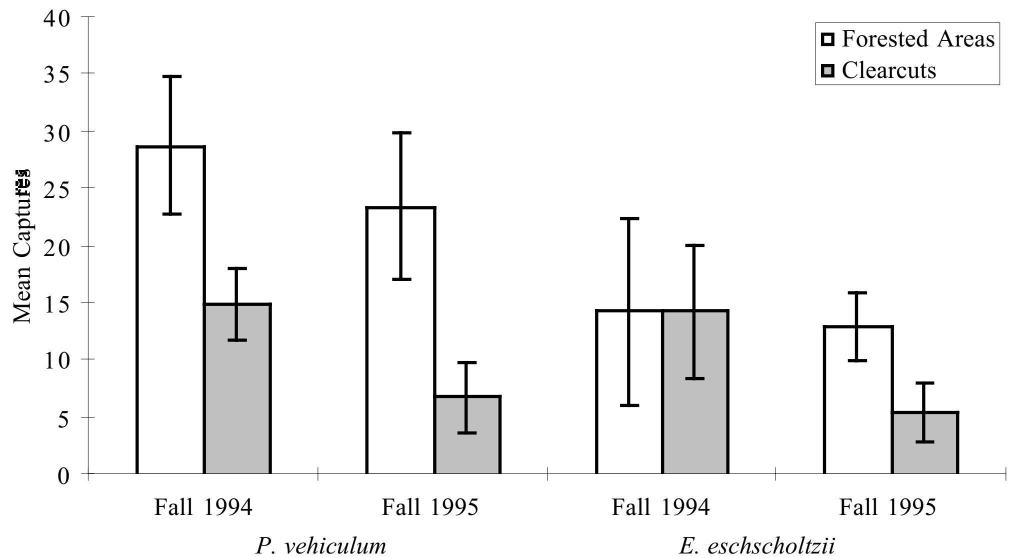
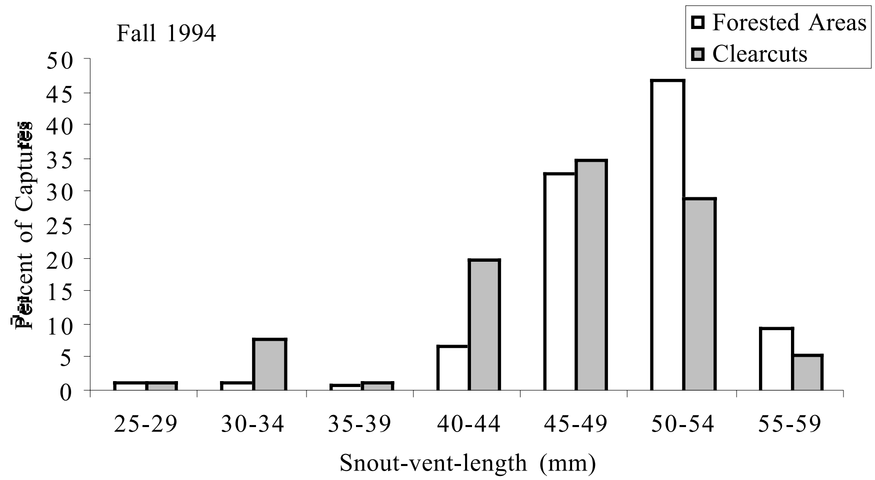


Fig. 1. Estimates of relative abundance (mean ± SD) of western red-backed salamanders and ensatinas captured in forested areas (n = 4) and clearcuts (n = 4) of Douglas-fir/western hemlock forests in Washington in fall 1994 and fall 1995.



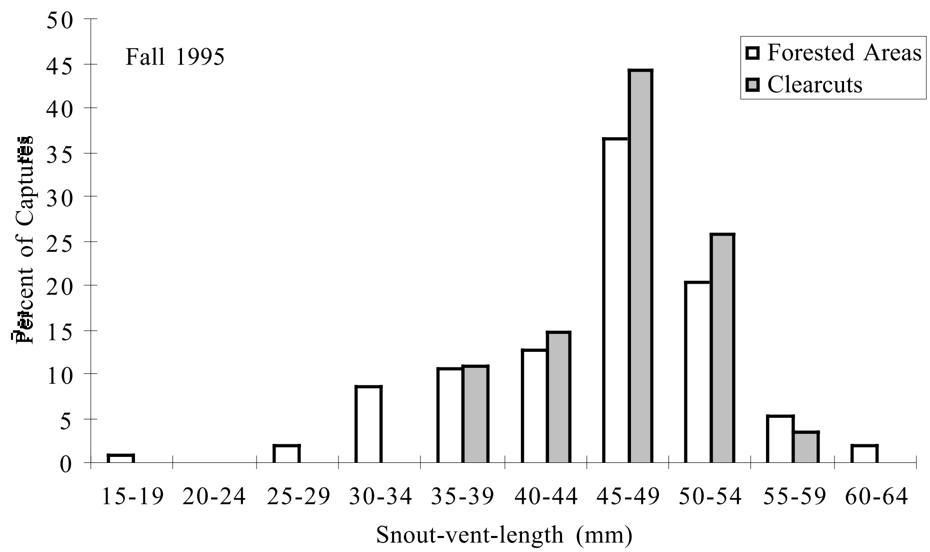


Fig. 2. Sizeclass distributions of western red-backed salamanders in forested areas (*n* = 4) and clearcuts (*n* = 4) of Douglas-fir/western hemlock forests in Washington in fall 1994 and fall 1995.

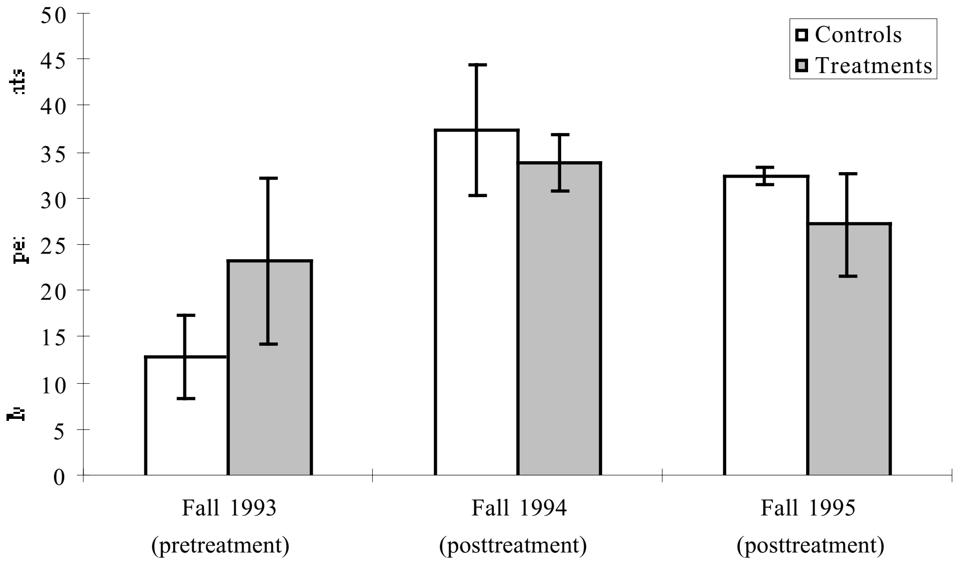


Fig. 3. Estimates of relative abundance (mean ± SD) of western red-backed salamanders captured in unthinned controls (*n* = 4) and thinned treatments (*n* = 3) in fall 1993 (pretreatment), fall 1994 (posttreatment), and fall 1995 (posttreatment) in Douglas-fir/western hemlock forests in Washington.