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Terrestrial and Stream Amphibians across Clearcut-Forest Interfaces in the Siskiyou Mountains, Oregon

Abstract

Timber harvest in the Pacific Northwest has resulted in a highly fragmented landscape, but there is no information on responses of amphibians to forest edges for this region. We investigated abundance of terrestrial and stream-dwelling amphibians on the interface of recent clearcuts and mature forest in the Siskiyou Mountains, Oregon, in summer and fall of 1998. We assessed relative abundance of terrestrial amphibians on four clearcut-forest transects with a combination of pitfall trapping and manual searches. *Ensatina* and Del Norte salamanders, the most frequently recorded species, were found on all four sites. While we commonly captured *ensatina*s using both techniques, we caught most Del Norte salamanders during manual searches. For both species we found no differences in abundance associated with distance to forest edge. Lack of differences in salamander abundance among clearcut and adjacent forests may be related to large amounts of small woody debris that remained in the clearcuts. The abundance of larvae of tailed frogs and Pacific giant salamanders in five headwater streams was markedly lower in clearcuts than in downstream mature forest stands. No obvious differences existed for stream habitat variables across transects, but abundance of metamorphosed individuals and recruitment may be reduced in clearcut areas due to hotter and drier conditions during the summer.

Introduction

Next to loss of forest habitat, the increasing proportion of edges is considered one of the most problematic consequences of forest fragmentation (Murcia 1995). Because forests abutting harvested areas are subject to changes in physical and biotic conditions, forest species may have reduced abundances or be excluded from edge habitats (Mills 1995, Jules 1998). This is especially true for species susceptible to the drier, warmer conditions typical of deforested areas and forest edges (Murcia 1995). Because of their ectothermal lifestyle and often low tolerance to high temperatures and water loss (Stebbins and Cohen 1995), many amphibians are negatively affected by timber harvest (deMaynadier and Hunter 1995).

In the Pacific Northwest, extensive timber harvest has occurred over the last 100 yr. Only about 17% of the pre-settlement coniferous forest has

not been logged (Spies and Franklin 1988), resulting in a high proportion of early-successional forest. Certain amphibian species in the region are associated with habitat conditions realized primarily in old-growth stands (Welsh 1990, Ruggiero et al. 1991). However, it is unknown whether increasing amounts of forest edges might further reduce the abundance and distribution of those species. While recent studies in the eastern United States have demonstrated that some amphibians are negatively affected by forest edges over relatively short distances (deMaynadier and Hunter 1998, Gibbs 1998) we are unaware of any published studies on the topic in the Pacific Northwest. Also, little is known about the effects of fragmentation and edge on stream amphibians. Although forest harvesting has negative impacts on many stream amphibians (Bury and Corn 1988, Corn and Bury 1989), it is unclear whether those impacts are limited to the harvested area itself or if they would also influence downstream areas.

We investigated the distribution of amphibians across clearcut-forest interfaces in the Siskiyou Mountains, Oregon, a region with a diverse and unique herpetofauna (Bury and Pearl 1999) and

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high levels of forest fragmentation (Jules et al. 1999). Our objectives were to compare the presence and abundance of terrestrial and steam amphibians in transects across recent clearcuts, the interface of forest edge, and late-successional forests.

Methods

Study sites were in the Siskiyou National Forest, located in the central part of the Siskiyou Mountains, southwestern Oregon (Figure 1). The climate in this area is Mediterranean with hot, dry summers and cool, moist winters. Almost all precipitation falls from October to May. Below about 1200 m, Douglas-fir (*Pseudotsuga menziesii*) and occasionally sugar pine (*Pinus lambertiana*) dominate the upper canopy. A lower canopy is formed by evergreen hardwoods such as tanoak (*Lithocarpus densiflorus*), Pacific madrone (*Arbutus menziesii*), chinquapin (*Castanopsis chrysophylla*), and canyon live oak (*Quercus chrysolepis*).

At higher elevations (>1200 m), hardwoods are scarce or absent and Douglas-fir is replaced by true firs (*Abies* spp.). At all but the highest elevations, Port Orford cedar (*Chamaecyparis lawsoniana*) and bigleaf maple (*Acer macrophyllum*) are found at sites with continual water supply, such as near springs and small streams (Whittaker 1960).

Terrestrial Sites

We maximized edge contrast by choosing four stands of uncut forest >180 yr old adjacent to clearcuts <15 yr old (Table 1, Figure 1). To fit several sampling plots and to provide a 50 m buffer from roads and streams, edges had to be at least 250 m long and relatively straight. Southern, drier aspects were not sampled. These constraints and the need for a daily site check during pitfall trapping precluded random site selection.

All four uncut forest sites were at least 13 ha (Table 1). This size was considered sufficient to

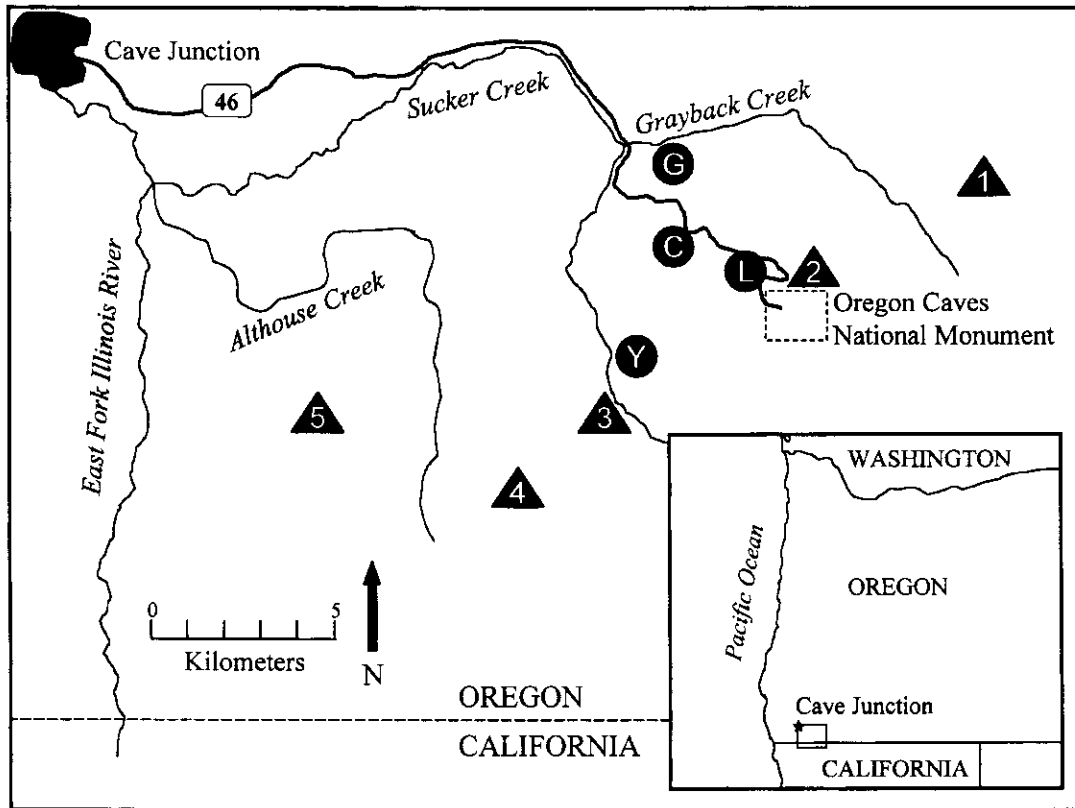


Figure 1. Study area in Siskiyou National Forest, southwestern Oregon showing locations of terrestrial (●) and aquatic (▲) study sites.

TABLE 1. Characteristics of forest stands and adjacent clearcuts surveyed for terrestrial amphibians on forest edges in Siskiyou National Forest, Oregon. Elevation was measured at approximate midpoint of surveyed length of edge.

Site	Age (yr)	Size (ha)	Elevation (m)	Slope (%)	Aspect	Bearing of edge	Size of cut (ha)	Year cut
L	>200	60	1020	50	N	ESE	5	1986
G	>200	34	810	46	NNE	SE	26	1986
C	>300	13	960	43	NE	SE	13	1986
Y	>180	21	960	31	W	S	6	1990

provide areas uncompromised by edges, based on a depth of influence of 25–65 m in previous work on forest amphibians in the eastern United States (DeGraaf and Yamasaki 1992, deMaynadier and Hunter 1998) and studies on small mammals and herbaceous species in the Siskiyou Mountains (Mills 1995, Jules 1998). After logging, all clearcuts had been burned and planted with Douglas-fir seedlings. Also, to reduce competition with the conifers, young hardwoods had been cut down repeatedly, resulting in large amounts of slash and small logs on the ground in the harvested stands.

At each site, we installed 15 pitfall traps, arranged in five parallel lines each containing three traps spaced 25 m apart. Lines were placed in the clearcut at 15 m and 45 m from the edge, and at 15 m, 45 m, and 75 m in the forest (Figure 2). Each trap was built from two number 10 tin cans taped together for a deep trap and included a plastic funnel (Corn and Bury 1990). We also added three drift fences pointing away from each trap in 120-degree angles (modified from Corn and Bury 1990) made of transparent polyethylene supported by wooden stakes. Fences were 3 m long and ~30 cm tall after being buried 10 cm deep in the ground. We opened traps for 61 consecutive days from 1 October to 1 December 1998. We checked traps daily in the early morning during times of high capture probability (immediately after trap opening and after rainfall) and every other day for the remaining time. We recorded species, sex, snout-vent length, and total length (both to the nearest mm) for every capture. The second toe on the left hind foot was clipped to recognize recaptures. We released animals immediately at about 5 m from the trap next to a cover object.

We also manually searched for amphibians on plots that were 50 m long (parallel to the edge) and 30 m wide. Plots were directly adjacent to each other to form a transect running from 60 m into the cut to 90 m into the forest interior. We sampled two such plot transects at each edge site

(Figure 2). We avoided patches that were structurally different (e.g. small wind throws), so that pitfalls grids and search transects were placed at variable distances from each other (5-500 m). Searching for amphibians combined time- and area-constrained sampling (Corn and Bury 1990). Four persons systematically searched through each 50 x 30 m plot for 1 hr (4 person hr). Starting at the downhill end of the plot, searchers moved uphill while turning all moveable cover objects including rocks, small logs, and pieces of bark on the ground. Well-decayed logs and the space between bark and log surface were also probed or separated. We spent ≤10 min searching any log to ensure an even distribution of search efforts (Corn and Bury 1990). We sampled all five plots in one transect in the same day. We searched sites twice on four consecutive days (18-21 and 25-28 November 1998) during wet and non-freezing conditions. We pooled numbers of animals found during both sampling sessions for each site.

Using line intersect sampling (DeVries 1974), we determined the amount of downed wood within each edge class, employing two 20-m line-intercept transects with random orientation with the midpoint of each line equidistant from two pitfall traps (Figure 2). For every log intersecting the line, we recorded length, diameter at both ends and the middle, type (hardwood or conifer), and degree of decay on a scale from 1 (mostly intact) to 3 (mostly decayed). Definition of a log followed Mills (1995) who included any dead woody material closer than 45° to the ground that was greater than 10 cm diameter at the larger end. Log volume (m³/ha) and log density (number/ha) were estimated based on the 40 m of total transect in each edge class (DeVries 1974, Mills 1995).

We measured temporal changes of topsoil moisture across the surveyed forest edges in June, July, August and October 1998, sampling three of the sites (all except Y) once a month, after at least 48 hr without rainfall. Sampling followed a

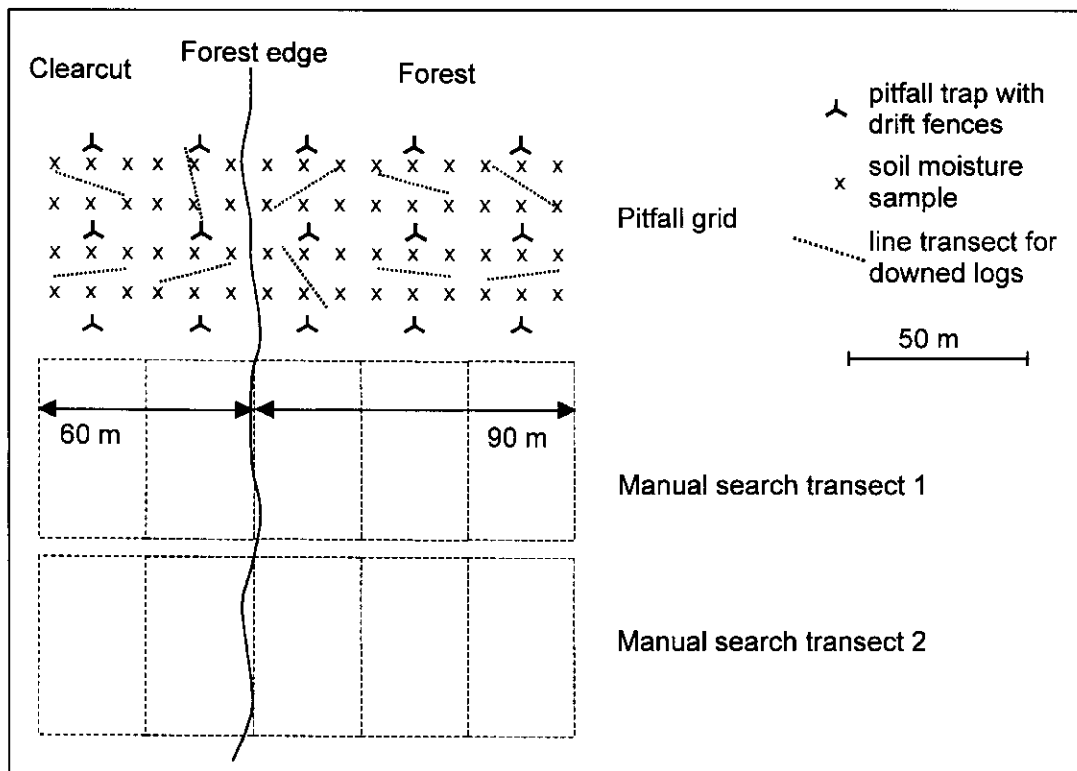


Figure 2. Schematic view of forest edges and spatial application of sampling procedures used. Distances between pitfall grid and manual search transects varied from site to site and are not shown to the actual scale.

systematic design with 12 soil samples spaced ca. 10 m apart within each edge class (= 60 samples per site and month). The exact sampling spot was determined by throwing a shovel over a shoulder. Each soil sample (32 cm³) was placed in a plastic container after removing visible rocks and coarse organic matter, and taken to the lab to be oven dried for 48 hr at 95° C. The difference between dry and fresh weight divided by the volume gave percent water content.

Stream Sites

To investigate the effects of forest edges on stream amphibians, we selected five headwater streams flowing from clearcuts into uncut stands of older forest (Figure 1). While specific estimates for forest age were not available, all stands represented late-successional forest. The adjacent stands had been clearcut 26-34 yr ago. Regeneration appeared to be slow and trees planted in the cut did not exceed 5 m in height. We chose only permanent first and second order headwater streams that had suf-

ficient water flow during the dry summer months to support stream amphibians. Average stream width varied from 1.1-2.0 m and elevation of the sites (as measured on the clearcut-forest boundary) was 750-1230 m. The streams lacked a buffer zone separating them from the clearcut area, but were usually shaded by small trees, mainly willows and alders (2-5 m high).

We defined the edge for streams as the straight line perpendicular to the stream that connected the two outermost mature trees (dbh >25 cm) of the forest within 15-50 m on each side of the stream channel. Trees closer than 15 m were excluded because some single trees close to the stream had been spared from logging. These trees would have put the edge far into the clearcut. Roads and forest of various ages were upstream of all clearcuts. At each site, we established five 5-m long sampling segments at the edge (0 m), and at 50 m and 100 m into clearcut and forest. If sampling segments were at unusual locations such as waterfalls or piles of logs, we moved sampling

segments ± 5 m away from the feature. We recorded general data on stream variables in July and August prior to the amphibian sampling. For every 1 m section of each 5 m segment we measured stream width and dominant substrate, and scored pool ratio based on a scale from 1 to 10 (Bury and Corn 1991). We estimated embeddedness of rocky substrate (>65 mm) with fine sediment on a scale from 1 (less than 20% covered) to 5 (at least 80% covered). For each segment, we recorded gradient of the stream and both side slopes and measured stream temperature.

Amphibian sampling followed the protocol of (Bury and Corn 1991) and occurred 23 July-15 August 1998 when weather conditions were hot and dry. A drift net (window screen, 2 mm mesh) was installed at the downstream end of the segment. We searched each segment in 1-m intervals, first by turning over rocks on the stream bank up to 50 cm away from the stream and then by searching the stream. We sampled by turning all moveable rocks and woody materials, removing them from the stream and placing them on the stream bank. A dip net or piece of hardware cloth was placed immediately downstream. Also, we frequently checked the drift net at the downstream end for dislodged animals. After sampling the 5-m area, we replaced cover and released all animals into the stream. We sampled all five segments per site consecutively starting from the downstream end (+100 m), and finished within 2-3 days. Captures are expressed as numbers per m^2 based on the measured widths for the sampled segments.

Data Analysis

Using an ANOVA procedure we tested the null hypothesis that biotic and abiotic variables (grouped in edge classes) remained constant across edges. Edge distance was thereby treated as a fixed main factor. Whenever the assumption of homogeneous variances was met, a two-way ANOVA was performed that added 'site' as a random factor for blocking (Sokal and Rohlf 1981). Otherwise, data were square root transformed {square root (x) + square root ($x+1$)}. If transformations failed to correct the problem, a one-way ANOVA robust to unequal variances (Rice 1989) was used instead. Due to the inability to block for site in this alternative procedure, the power to detect differences associated with edge distance declined

considerably. We refer to the resulting P -values of either test as $P_{distance}$.

Next, we asked whether differences between edge classes occurred at random or if they had a directional component in being ordered in a consistent fashion. The ordered heterogeneity test (Rice and Gaines 1994) specifically addresses this aspect of directionality and has been successfully applied in previous edge studies (Mills 1995). In this procedure, the result of a heterogeneity test (e.g., an ANOVA P -value) is combined with an order component (rank correlation) to calculate a final P -value. We computed Spearman's rank correlation between edge distance and means for this purpose and used the $P_{distance}$ value calculated in the ANOVAs described above. Results from the ordered heterogeneity test are designated as P_{edge} .

To account for the inflated Type I error arising from testing the same alternative hypothesis (edge trend) repeatedly, we performed a sequential Bonferroni correction (Rice 1989) of P -values for each group of tests (terrestrial salamanders, soil moisture levels, coarse woody debris, stream variables, and stream amphibians). We considered a probability level of ≤ 0.05 as significant.

Results

Terrestrial Forest Edges

We captured 98 individuals of six amphibian species in pitfall traps (Table 2). Numbers varied among sites from 9 to 37 captures. *Ensatina* (*Ensatina eschscholtzii*) was the most common species, representing 75% of all captures. *Ensatina* and Del Norte salamander (*Plethodon elongatus*) were the only species caught at all four sites. All other amphibian species were caught in low numbers (<10) at between one and three of the sites (Table 2).

In 160 person hours of manual search, we caught 165 amphibians of which most (99%) were plethodontid salamanders (Table 2). *Ensatina* was the most common species found with this technique; 80% of captures were in or under logs. We also frequently found Del Norte salamanders, predominantly beneath rocky substrate (60%) and to a lesser degree under logs or bark on the ground (30%). Both species were detected at all four sites. We captured 7 of 12 clouded salamanders (*Aneides ferreus*) near the forest edge, mainly in association with logs.

TABLE 2. Mean amphibian captures (\pm SE) using live pitfall trapping and hand collection across four forest edges at Siskiyou National Forest, Oregon, fall 1998. N = total number of individual captures. Edge distance refers to the perpendicular distances from the edge into clearcut (negative values) or forest (positive values).

Species	Sampling	N	Sites	Edge distance (m)					P_{distance} ^a	Rank ^b	P_{edge} ^c
				-45	-15	+15	+45	+75			
Pacific giant salamander	Pitfall	8	3	0.0 (0.0)	0.3 (0.3)	0.3 (0.3)	0.5 (0.3)	1.0 (0.7)	-	-	-
	Search	-	-	-	-	-	-	-	-	-	-
Ensatina	Pitfall	70	4	4.5 (1.3)	5.8 (2.1)	2.5 (0.6)	1.5 (1.0)	3.3 (1.3)	0.041	-0.60	0.102
	Search	90	4	2.8 (0.6)	3.5 (0.8)	4.0 (0.8)	7.3 (2.8)	5.0 (1.7)	0.921 ^d	0.90	0.284
Del Norte salamander	Pitfall	8	4	0.3 (0.3)	0.5 (0.3)	0.8 (0.3)	0.3 (0.3)	0.3 (0.3)	-	-	-
	Search	62	4	3.0 (2.0)	4.5 (1.6)	3.5 (1.8)	2.3 (1.0)	2.3 (1.0)	0.578	-0.67	0.348
Clouded salamander	Pitfall	1	1	0.0 (0.0)	0.3 (0.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	-	-	-
	Search	12	3	0.3 (0.2)	0.8 (0.4)	1.0 (0.5)	0.8 (0.4)	0.3 (0.2)	-	-	-
Rough-skinned newt	Pitfall	5	2	0.3 (0.3)	0.3 (0.3)	0.3 (0.3)	0.3 (0.3)	0.3 (0.3)	-	-	-
	Search	-	-	-	-	-	-	-	-	-	-
Tailed frog	Pitfall	6	2	0.3 (0.3)	0.0 (0.0)	0.3 (0.3)	0.0 (0.0)	1.0 (0.6)	-	-	-
	Search	1	1	0.0 (0.0)	0.3 (0.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	-	-	-

^aTwo-way ANOVA testing for main effect of edge distance while using site as a blocking term.

^bSpearman's rank coefficient for mean captures relative to edge distance.

^cOrdered heterogeneity test (Rice and Gaines 1994) after sequential Bonferroni correction for multiple tests (Rice 1989).

^dOne-way ANOVA robust to heterogeneous variances used with edge distance as the only explanatory variable

The proportion of adult (>50 mm) to juvenile ensatinas caught in pitfalls (73: 27) was higher than found with manual searches (40:60). Searches also yielded fewer adult than immature Del Norte salamanders (40:60); pitfall captures were too low for such a comparison in this species. Age proportions among edge classes did not differ significantly for ensatinas in pitfalls ($P = 0.980$) or manual searches ($P = 0.209$), nor for Del Norte salamanders in manual searches ($P = 0.240$).

Owing to small sample sizes for most species, tests for an edge trend were only performed for ensatinas (data from pitfalls and manual searches) and for Del Norte salamanders (manual searches only). None of those tests identified a significant trend in relative abundance across the clearcut-forest gradient (Table 2). Notably, the higher number of ensatinas caught in pitfalls in clearcuts suggested a trend opposite to that based on manual searches, during which ensatinas were more commonly found in the forest.

Quantities of downed wood were significantly greater in the clearcut compared to the forest for both volume ($P = 0.026$) and density of logs ($P = 0.014$) (Figure 3). Specifically, several hundred cubic meters per hectare were estimated for the logged area compared to $\sim 100 \text{ m}^3$ in the forest. We also noted a marked contrast for number of logs with 2000-3000 per ha in clearcuts and ~ 200 per ha at 75 m into the forest. Within the forest,

areas closer to the edge had more logs on the ground compared to the forest interior, but volume of downed wood was uniform across the same spatial scale. The vast majority of logs on all sites comprised moderately decayed hardwoods.

Soil water content in June was relatively uniform across the clearcut-forest transect with values ranging around 35%. Then, moisture diminished quickly and average water content fell to 17-21% in July and 10-15% in August. In summer, values generally were lower in clearcuts than in the forest. In late October, after the onset of autumn rainfall, this trend was reversed and water content was >38% in the clearcut compared to $\sim 30\%$ in the forest. While differences among edge classes were pronounced in July, August, and October, there was no significant directional trend across edge classes after correcting for multiple testing (all $P = 0.080$).

Stream Sites

We found two species of stream amphibians at all sites. Densities of tailed frog tadpoles (*Ascaphus truei*) were generally higher within forests including the edge compared to clearcuts (Figure 4). Adult and subadult frogs were uncommon and differences in numbers were less pronounced across edges. A high level of variation in tadpole densities across sites was caused by rarity of tadpoles in one of the streams.

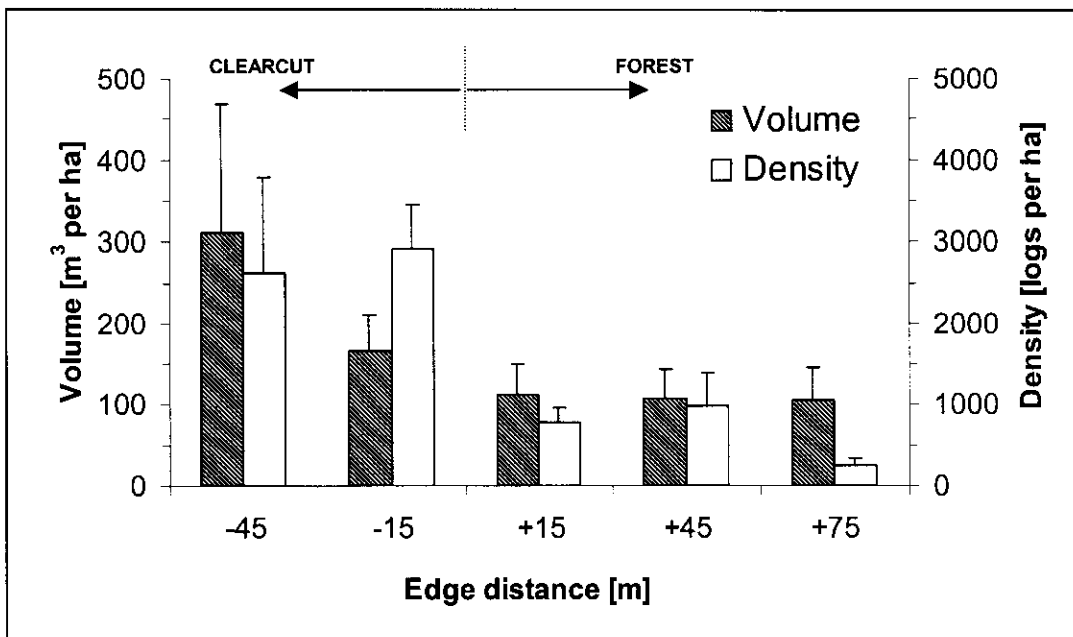


Figure 3. Estimated means (\pm SE) of density and volume of coarse woody debris across four clearcut-forest gradients, Siskiyou National Forest, Oregon, 1998.

Although Pacific giant salamander (*Dicamptodon tenebrosus*) larvae were more common in clearcuts than were tailed frog larvae, their densities also increased toward the forest interior (Figure 4). There was a significant negative trend from forest to clearcut for tailed frogs ($P = 0.022$) and nearly so for Pacific giant salamanders ($P = 0.054$).

We also encountered 32 metamorphosed tailed frogs during the searches (26 adults, 6 juveniles). Numbers per m^2 averaged 0.11 in the clearcut, 0.18 for the edge, and 0.21 for the forest interior (Figure 4). Because sample size was small and we are unsure whether the proportion of the frogs hiding in the stream remained constant across the edge transect, we did not subject these data to a test of edge trend.

No significant differences in gradient (percent drop), dominant substrate, pool ratio, embeddedness with fine sediment, water temperature, side slope, or canopy cover were found among the segments sampled within streams (Table 3). Canopy cover was highly variable in clearcuts, ranging from 28% to 95%, and no significant differences in canopy cover were found overall among edge classes. This was because along some streams small trees in the clearcut area provided shading.

Discussion

Terrestrial Sites

We obtained sample sizes sufficient for analysis for only two species of woodland salamanders. Members of this group are considered sensitive to the effects of timber harvesting (deMaynadier and Hunter 1995, Welsh and Droege 2001).

Ensatina is a widespread salamander in the Pacific Northwest, occupying a variety of forest habitats (Nussbaum et al. 1983). It occurs in oak woodland in California and, in the Pacific Northwest, reaches highest abundances in dry old-growth stands (Aubry and Hall 1991, Welsh and Lind 1991). Thus, it may have a relatively higher tolerance to high temperatures and low moisture compared to other western salamanders. Although usually not considered a species threatened by forest harvesting, positive associations with stand age were suggested for ensatinas in some areas (Raphael 1988, Welsh and Lind 1991, Aubry 2000).

Many studies suggest that structural features rather than stand age might influence the local abundance of woodland salamanders. Ensatinas, specifically, appear to have strong associations

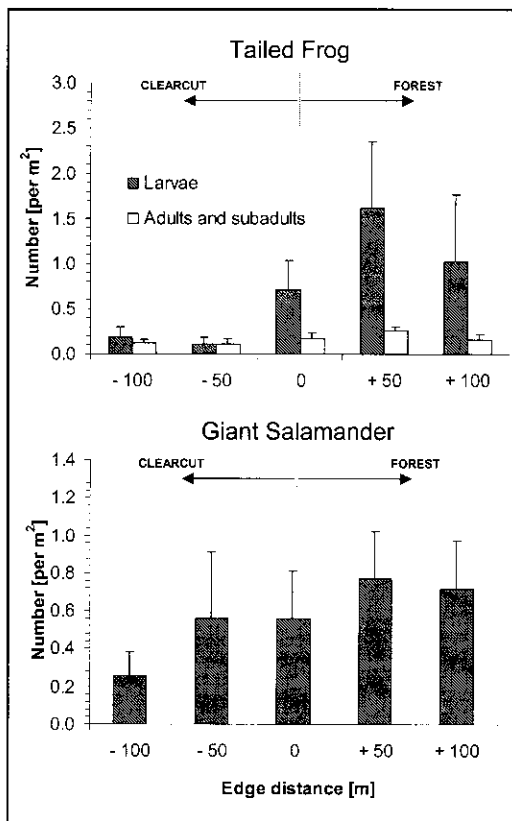


Figure 4. Densities (\pm SE) of tailed frogs and Pacific giant salamanders in five headwater streams flowing from clearcuts into downstream mature or old-growth forest in the Siskiyou National Forest, Oregon, 1998.

with woody debris (Butts and McComb 2000), including small logs (Welsh and Lind 1991). Volume and density of decaying logs were much higher in clearcuts than in adjacent forests (Figure 3), as a result of cutting undesired hardwoods in regenerating Douglas-fir stands. These large amounts of downed wood may be a beneficial habitat feature for ensatinas in clearcuts by providing shade and cover. This may allow the ensatina in the Siskiyou to inhabit forest edges and harvested stands to a similar level as contiguous forest.

Most ensatina captures in pitfalls occurred in clearcuts whereas capture rates were higher inside the forest during manual searches (Table 2). Our monitoring of soil moisture content indicated that the forested portion of the edge transect received less precipitation after the onset of rainfall in October than the adjacent clearcut, clearly a result of the intercepting canopy cover in forests. Thus, pitfall captures may have been higher in the clearcut due to microclimatic conditions there permitting surface activity earlier than in the forest.

The Del Norte salamander is endemic to the Siskiyou region (Nussbaum et al. 1983). Rocky substrates are an important habitat prerequisite for its occurrence (Herrington 1988, Welsh and Lind 1995) and its highest densities are usually found in old-growth stands (Raphael 1988, Welsh 1990, Welsh and Lind 1991, 1995). In contrast, Diller and Wallace (1994) found no correlation between Del Norte salamander occurrence and

TABLE 3. Habitat variables measured in five streams at same edge distances sampled for amphibians. Shown are means (\pm SE). Differences between means were tested with two-way ANOVA (except where indicated) with site as block and site by edge distance as error terms. *P*-values shown are corrected for multiple testing of the hypothesis of edge differences. Proportions were arcsine transformed prior to analysis.

	Edge distance (m)					<i>P</i>
	-100	-50	0	+50	+100	
Stream gradient (%)	11.0 (0.8)	11.0 (1.6)	15.8 (5.5)	9.2 (1.2)	8.0 (1.1)	0.826
Dominant substrate ^a	8.6 (0.5)	8.8 (0.4)	9.0 (0.2)	8.6 (0.2)	8.8 (0.1)	0.971
Pool ratio ^b	4.3 (0.5)	4.8 (0.4)	3.4 (0.3)	3.7 (0.5)	4.7 (0.4)	0.378
Embeddedness ^c	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)	—
Side slope	39.0 (3.6)	39.9 (7.6)	36.6 (3.8)	39.0(5.5)	36.4 (1.8)	0.980
Water temperature (°C)	15.0 (1.3)	14.6 (1.1)	14.3 (1.0)	14.4 (1.0)	14.3 (0.7)	0.837
Canopy cover (%)	59 (13)	69 (12)	76 (6)	86 (3)	84 (3)	0.680 ^d

^aMean size of dominant substrate on scale from 1 (silt/clay) to 10 (> 256 mm)

^bProportion covered by pools on scale from 1 (all riffle) to 10 (all pool)

^cDegree of sedimentation with fine substrates on a scale from 1 (<20%) to 5 (>80%)

^dOne-way ANOVA used due to heterogeneous variances

forest age or canopy cover in a marine-influenced, moister study area located closer to the coast. These data suggest that in inland regions, Del Norte salamanders could likely be affected by clearcuts and forest edges. However, we found no differences in relative abundance among clearcut, forest edge, and forest interior for this species. Like ensatinas, we suggest that large amounts of woody debris maintain tolerable conditions for the Del Norte salamander in clearcuts. We caution, however, that our inference is limited to one year of data collected at few sites on north- and west-facing slopes. We are unable to draw conclusions about edge effects at other aspects. Also, we cannot rule out that edge effects reach even farther into the forest than the 90 m we sampled, as has been found for several abiotic variables (Chen et al. 1995). Finally, Del Norte salamanders were not abundant on any of our four sites, based on an average of 0.4 individuals found per person hour of search. This number is low compared to >4 salamanders per person hour found in some mature forests (Welsh and Droege 2001).

We also found constant proportions of adult and immature ensatinas and Del Norte salamanders across edge classes, showing that location relative to the edge did not affect population structure in either species. Similarly, Grialou et al. (2000) reported equivalent size distributions of ensatinas in clearcuts and adjacent forests.

Although limited in scope, our study suggests that terrestrial salamanders in the Siskiyou Mountains were not negatively affected by forest edges on northern and western slopes and for distances up to 90 m into the forest interior. This may also mean that smaller clearcuts with such exposure do not represent dispersal barriers for those species.

Stream Sites

We found a difference of larval densities across the clearcut-forest interface for both species of stream-dwelling amphibians with lowest numbers at the farthest distance into the clearcut area. Tailed frogs depend on cool, fast-flowing streams, and are sensitive to impacts of timber harvest (Bury and Corn 1988, Dupuis and Steventon 1999). In southwest Oregon and northwest California, 81% of streams flowing through old-growth forests had tadpoles compared to only 11% of streams in young stands (Welsh 1990). However, Diller and Wallace (1999) reported that tailed frog populations in the

milder Californian coastal belt were associated with substrate parameters and gradient rather than forest age or canopy closure.

Association with forest age is less clear for Pacific giant salamanders. Adults are equally common in naturally regenerated forests of young, mature, and old age (Corn and Bury 1991, Welsh and Lind 1991). Larval densities also did not differ with forest age in unmanaged uncut forest (Bury et al. 1991), but were reduced in logged areas compared to uncut forest and especially in low gradient streams (Corn and Bury 1989). In contrast, two studies reported higher salamander densities or biomass after logging, probably due to a temporary increase in productivity and prey base (Murphy and Hall 1981, Hawkins et al. 1983).

We found that larval densities decreased with increasing distance from the downstream forest. Since stream habitat and temperature were not appreciably different across the 200 m clearcut-forest transect, other factors are likely responsible for these differences. We suggest that the observed patterns could be explained by the terrestrial habitat requirements of Pacific giant salamanders and tailed frogs. Metamorphosed Pacific giant salamanders appear to depend on cool and moist conditions (Welsh and Lind 1991, Gomez and Anthony 1996), and immediate responses of terrestrial adults and juveniles to clearcutting may be negative (Cole et al. 1997). Abundance of larvae also increases with the amount of large woody debris available close to the stream, possibly because such logs provide important cover for adults (Wilkins and Peterson 2000). Also, adult tailed frogs have low tolerance to dry conditions and high temperatures (Claussen 1973a,b). These data suggest that clearcuts may provide unsuitable habitat for the terrestrial stages of both Pacific giant salamander and tailed frog. Consequently, a locally lower density of adults would reduce recruitment and larval densities of streams flowing through clearcuts.

The suggested explanation would imply that movement of amphibians from forest into the upstream clearcut during reproduction is limited. Indeed, extreme philopatry is typical for the tailed frog and only immature frogs disperse over several hundred meters (Daugherty and Sheldon 1982). Aubry (2000) caught few juvenile and adult tailed frogs in managed forests compared to unmanaged stands, and he suspected that local extinctions from

streams in harvested stands may be related to restricted movements of frogs through managed upland habitat. Our results for stream amphibian captures in pitfall traps were consistent with the hypothesis of higher abundance under closed canopies since the majority of tailed frog and Pacific giant salamander captures occurred in the forest interior (Table 2).

Dispersing tailed frogs and Pacific giant salamanders may be able to traverse clearcuts during environmentally favorable conditions. However, some data from the eastern U.S. suggest that forest edges may limit movements of dispersing amphibians (Gibbs 1998) and that especially newly metamorphosed individuals prefer closed canopy situations (deMaynadier and Hunter 1999). The question of which factors contribute to successful dispersal and colonization of amphibians in the Pacific Northwest deserves particular attention by wildlife research and management.

Effects of future harvesting on larvae of stream amphibians may be a lesser problem because riparian buffers are now being left along many Northwest streams. Such buffers appear to be effective in mitigating the effects of harvesting on stream amphibians in British Columbia (Dupuis and Steventon 1999), but are less well studied farther south. Still, new regulations are primarily

intended to maintain conditions within the stream and on the stream bank. Whether such buffer zones will also provide sufficient habitat for the terrestrial life stages of stream amphibians is unclear. For stream amphibians in the Pacific Northwest, edge effects may be of concern, especially in landscape situations where forested buffer strips are still lacking or where local recolonization will depend on movement through harvested upland habitats.

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