Salamander Abundance and Amphibian Species Richness in Riparian Buffer Strips in the Oregon Coast Range

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ABSTRACT. Logging and other forest practices are widely reported to be a threat to some amphibian populations in the Pacific Northwest. Riparian buffer strips are one conservation measure that may benefit amphibians in managed forests. However, few amphibian surveys have been conducted in buffer strips. We compared total salamander abundance, amphibian species richness, and sampling proportions for five species of salamanders between 17 managed stands and 12 unlogged, streamside forests in the Coast Range of western Oregon. We also identified relationships between buffer strip width and salamander population indices. Surveys conducted on 20 × 40 m plots demonstrated that torrent salamanders (*Rhyacotriton* spp.), clouded salamanders (*Aneides ferreus*), Dunn's salamanders (*Plethodon dunni*), western red-backed salamanders (*Plethodon vehiculum*), total salamander abundance, and amphibian species richness were sensitive to forest practices in riparian areas. We conclude that riparian buffer strips are a useful habitat management strategy for several salamander species. However, buffer strip widths currently required by state forest practices regulations may not be adequate to prevent local declines in the diversity of amphibian communities. For. Sci. 48(2):291–297.

Key Words: Clearcut, forest management, habitat associations, *Plethodon,* visual encounter surveys.

Riparian buffer strips have been used to protect water quality and aquatic ecosystems in managed forests for more than two decades. Most amphibian species that inhabit montane ecosystems in the Pacific Northwest are strongly associated with streams and riparian forests (Brown 1985, McGarigal and McComb 1993). Thus, buffer strips could potentially play an important role in the conservation of amphibian biodiversity in managed forests. However, buffer strips were originally conceived as a management practice to prevent elevated water temperatures after tree harvest and to protect salmon spawning habitat by intercepting fine sediments caused by soil erosion during logging and road-building. It is unclear whether buffer strips designed for these purposes are adequate to protect amphibian populations inhabiting streamside forests.

Many recent studies have implicated tree harvesting and other forest management practices as a major cause of habitat loss or declining habitat quality for terrestrial amphibians (Bury 1983, Petranka et al. 1993, Dupuis et al. 1995, Ash 1997). Clearcut logging has a particularly severe impact on salamander populations, at least in the short term. A review of 15 amphibian studies by deMaynadier and Hunter (1995) showed that the abundance of plethodontid salamanders in clearcuts averaged only 20% of that in control stands. We are not aware of any previous research conducted specifically to examine the effect of buffer width on salamanders. However, findings from other amphibian studies suggest that retention of overstory trees will improve population indicators for

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Table 1. Descriptions of 14 forest attributes measured at 29 riparian study sites in the Coast Range of Oregon surveyed during 1994–1995. Log decay classes are modified from Maser et al. (1979).

Attribute	Description
LITTER DEPTH	Depth to O_2 horizon
%GRASS	% cover on 2 × 2 m plot; combined grass species
%HERB	% cover on 2 × 2 m plot; combined herbaceous species
%FERN	% cover on 2 × 2 m plot; combined fern species
%MOSS	% cover on 2 × 2 m plot; combined moss species
%BARK	% cover on 2 × 2 m plot; bark flakes detached from logs
%CANOPY	% cover; spherical densiometer measurement
LOG10–29	Sum length of logs (m) on a 10 × 10 m plot; diameter class 10 cm – 29 cm
LOG30–59	Sum length of logs (m) on a 10 × 10 m plot; diameter class 30 cm – 59 cm
LOG60–99	Sum length of logs (m) on a 10 × 10 m plot; diameter class 60 cm – 99 cm
LOG≥100	Sum length of logs (m) on a 10 × 10 m plot; diameter class ≥100 cm
LOGHARD	Sum length of logs (m) on a 10 × 10 m plot; decay class 1
LOGMED	Sum length of logs (m) on a 10 × 10 m plot; decay class 2–3
LOGSOFT	Sum length of logs (m) on a 10 × 10 m plot; decay class 4–5

salamanders (Petranka et al. 1993, Ross et al. 2000). Since much of the overall amphibian diversity is concentrated in riparian areas, buffer strips may be a particularly effective conservation strategy. To better understand the relationship between buffer strip width and salamander abundance, we conducted an observational study in managed and unlogged streamside forests. We hypothesized that indicators of salamander abundance and amphibian community diversity would exhibit a positive association with buffer strip width along headwater streams. Our specific objectives were to (1) assess the association between riparian buffer strip width and total salamander abundance, amphibian species richness, and occurrence of salamander species (2) compare the abundance of coarse woody debris and other attributes of forest floor structure between unlogged forests and buffer strips, and (3) describe the distribution of salamander species along a transriparian (i.e., stream edge-upslope) axis in unlogged forests so that buffer strip widths could be better prescribed to protect amphibian diversity along headwater streams.

Study Area

The study was conducted in the Coast Range of Oregon between 45°2′–44°12′ degrees latitude and between 60–480 m elevation above sea level. Study sites were within the *Tsuga heterophylla* Forest Zone (Franklin and Dyrness 1988) and were typically dominated by Douglas-fir (*Pseudotsuga menziesii*) or western hemlock (*Tsuga heterophylla*). Subdominant tree species included western redcedar (*Thuja plicata*), big-leaf maple (*Acer macrophyllum*), and red alder (*Alnus rubra*). The forest landscape pattern in the study area was dominated by private and public Douglas-fir plantations <80 yr old. Older stands were rare on privately owned lands. However, most of the federally administered forests in the study area have been managed as late-successional or riparian reserves since 1994.

Methods

Study Site Selection

We selected 17 managed stands and 12 unlogged streamside forests along 1st-, 2nd-, or 3rd- order permanent streams as represented on 1:24,000 scale, United State Geological Survey topographic maps. Managed stands were selected with the assistance of district biologists to represent a range of headwater buffer strip widths and conditions typically found in forests administered by the USDA Forest Service (USFS), Bureau of Land Management (BLM), or on private lands under Oregon forest practices rules. Each of the managed stands had been clearcut <5 yr before the surveys. Buffer strip widths at the managed stands ranged from 0 to 64 m (median = 21 m) as measured by the distance from the stream to the edge of the reserved vegetation >4 m in height on one side of the stream. Buffer strip study sites had trees retained on both sides of the active channel. The Oregon Forest Practices Act allows tree harvest to occur in buffer strips as long as a minimum basal area requirement is satisfied (Oregon Department of Forestry 1997). However, we excluded buffered sites that had evidence of tree harvest or excessive soil disturbance so these factors would not confound the effect of buffer strip width that was our primary question of interest. Unlogged study sites were greater than 100 yr old as indicated on USFS or BLM timber type maps, or were dominated by conifers having an average diameter >50 cm diameter breast height (dbh) as estimated during field inspection. Sampling plots were greater than 200 m from roads or stand boundaries.

Sampling Forest Floor Attributes

We measured 14 forest floor attributes (Tables 1 and 2) at four systematically selected 10 × 10 m quadrats at each plot. We measured the length (m) of all logs within the quadrat having a diameter >10 cm in four diameter (cm) classes (i.e., 10–29, 30–59, 60–99, ≥100). Logs were assigned to diameter classes based on the midpoint diameter of the portion of the log lying within the plot. Logs were also assigned to one of three wood decay classes (hard, medium, soft) as modified from Maser et al. (1979). Log lengths were summed among quadrats in a plot for a total abundance estimate in each class. Forest floor cover types were estimated ocularly on a 2 × 2 m subplot positioned at a randomly selected corner of the 10 × 10 m quadrat. Litter depth was measured at each of the corners of the 2 × 2 m subplot. Canopy closure was estimated from the average of four measurements taken with a spherical densiometer at the center of the quadrat.

Table 2. Means and standard errors of habitat attributes estimated from measurements in 17 riparian buffer strips and 12 unlogged riparian forests in the Coast Range of Oregon during 1994–1995. *P*-values are for tests of equality of means based on one-way analysis of variance *F*-tests.

Attribute	Buffer strips	Unlogged forests	*P*-value
LITTER DEPTH	31.3 (5.7)	36.5 (6.7)	0.558
%GRASS	1.6 (0.5)	1.2 (0.4)	0.621*
%HERB	10.6 (1.9)	16.1 (2.7)	0.101
%FERN	21.1 (4.8)	42.0 (3.2)	0.002*
%MOSS	9.0 (1.8)	16.7 (2.7)	0.027*
%BARK	1.5 (0.6)	1.5 (0.4)	0.969
%CANOPY	29.1 (5.7)	43.9 (4.0)	0.043*
LOGHARD	6.1 (1.7)	5.9 (2.4)	0.960
LOGMED	8.8 (1.8)	12.9 (3.0)	0.226
LOGSOFT	6.9 (1.7)	11.4 (2.5)	0.128
LOG10–29	9.5 (2.2)	9.1 (1.1)	0.884*
LOG30–59	7.0 (1.5)	8.3 (1.4)	0.563
LOG60–99	3.6 (0.8)	8.2 (2.6)	0.117*
LOG≥100	1.7 (0.8)	4.7 (2.3)	0.245*

Amphibian Surveys

Surveys for amphibians were conducted on three 20 × 40 m plots to distribute sampling effort across each study site. Plot locations were positioned at randomly selected distances along the stream; however, our randomization procedure prevented plots from being closer than 20 m to one another, and at least one plot had to be on each side of the stream. The lower side of each plot was generally <1 m from the active channel and the long axis of the plot was parallel to the aspect of the hill slope. Plots were subdivided into eight 10 × 10 m quadrats to equalize amphibian search effort across the whole plot and so that we could assign each amphibian detection to one of four distance-from-stream classes (i.e., 0–10, 10–20, 20–30, 30–40 m).

Amphibian sampling was conducted during April–May and November–December 1994, and March–May 1995. Each site was sampled once during the stndy and all plots at a site were surveyed on the same day (with one exception). The order of study site visits was determined by random assignment among the three sampling periods. We sampled amphibians using visual encounter surveys (Crump and Scott 1994) with a 30 min. search constraint per qnadrat. Thus, the total search time was 4 hr per plot and 12 hr per study site. The total search effort on a plot was divided between two surveyors to minimize the effect of individual surveyor biases on plot-level counts within a study site. Each surveyor used a stopwatch to monitor time and stopped the watch whenever the survey was interrupted (e.g., to identify captnred amphibians). Surveyors used pry bars to excavate logs and loosen rocks during their search. Amphibians were held in plastic bags containing damp moss until the survey was completed on a plot, then the animals were released on the quadrat where they were captured.

Data Analysis

We used SAS JMP version 3.0 software to conduct all data analyses (SAS Institute 1997). The significance level was set at $P \leq 0.10$ for all comparisons aud effect tests made in this study. We used analysis of variance to test the equality of means for forest floor attributes and canopy closure between buffer strips and unlogged riparian forests. For this comparison, we included only measurements from quadrats in managed stands having center points inside the mean buffer strip at the plot. Quadrats having center points outside the mean buffer strip width were considered to be harvested and excluded from this analysis. Before analysis of variance, we tested each dependent variable to determine if it met the assumption of homogeneity of variance between treatments (Levene 1960). Variables that conformed to the assumption of equal variance were tested for equality of means between treatments using conventional *F*-tests. We stabilized the variance for variables that did not meet this assumption by weighting the means of each treatment using the inverse of the sample variance in the analysis (Sabin and Stafford 1990, p.19–26).

We used the sum of all salamanders counted at a study site as an index of total salamander abundance. Amphibian species richness was defined as the total number of amphibian species observed at a study site. We used simple linear regression to examine the effect of buffer width on total salamander abundance and amphibian species richness at managed sites. We tested the statistical significance of buffer width in these models using least sum-of-sqnares *F*-tests. Unlogged forest sites were excluded from this analysis. We tested the dependent variables for normality using Shapiro-Wilks tests and examined residual plots for evidence of nonconstant variance. However, results of these goodness-of-fit tests did not indicate transformation was warranted. We used logistic regression (Hosmer and Lemeshow 1989) to identify relationships between buffer width and the odds of salamander species detection. Western red-backed salamanders occurred at all study sites, thus odds of detection was not a useful dependent variable for examining species response to buffer width. Instead, we used the total count of western red-backed salamanders at a site as the dependent variable and used simple linear regression methods similar to those used in the total salamander abundance analysis.

We used one-way analysis of variance to test the equality of means for indices of total salamander abundance and amphibian species richness between the 17 managed sites and the 12 unlogged forests. We used similar methods to compare forest floor attributes and to test for homogeneity of variance and to weight treatment means when necessary. To test that the probability of occurrence for each salamander species differed between managed riparian areas and unlogged forests, we used Fisher's exact test (Steel and Torrie 1980) to compare the sample probabilities between managed sites and unlogged forests. We tested the strength of evidence for gradients of population abundance along the transriparian axis by conducting Kruskal-Wallis rank sum tests on frequency of detections for each species in four distance-from-stream classes (i.e., 0–10, 10–20, 20–30, 30–40 m). Only data from unlogged study sites were used for this analysis because our objective was to describe transriparian population gradients in areas relatively undisturbed by forest management practices.

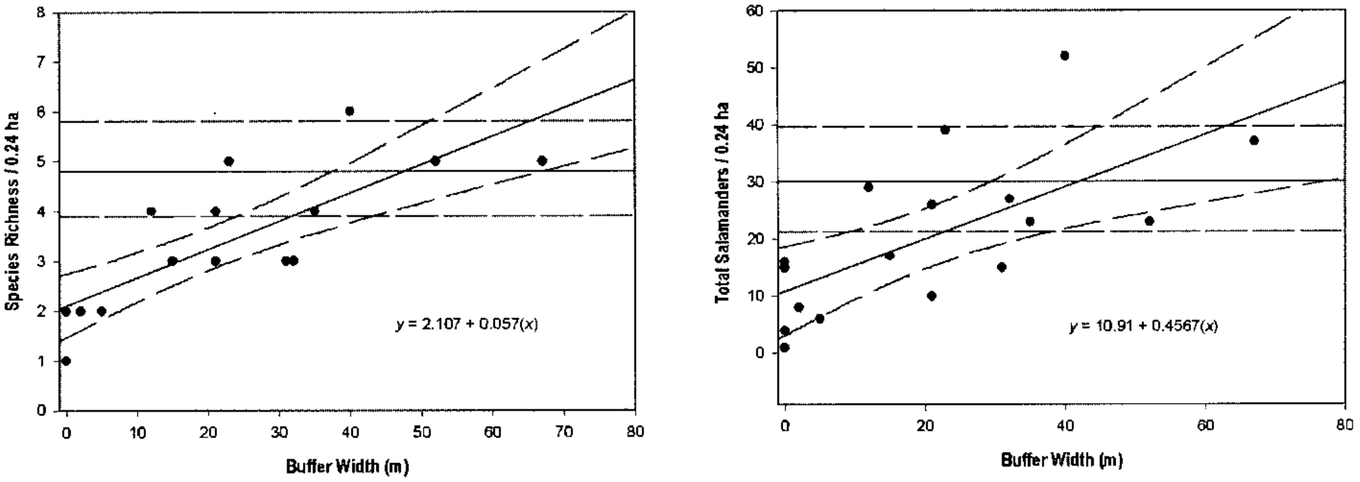

Figure 1. Relationships between buffer strip width (m) and amphibian community characteristics at 17 sites in the Coast Range of Oregon surveyed during 1994–1995. Solid horizontal lines indicate the mean value of each community characteristic in unlogged riparian forests (n = 12). Dashed lines indicate the 95% confidence intervals. (A) Relationship between buffer strip width and amphibian species richness. (B) Relationship between buffer strip width and total salamander abundance.

Results

We recorded 736 individual amphibians of 10 species during surveys of riparian areas. Four species were strictly terrestrial: clouded salamander, ensatina (*Ensatina eschscholtzii*), Dunn's salamander, and western red-backed salamander. We also analyzed pooled data from two species of torrent salamanders (*Rhyacotriton variegatus* and *R. kezeri*). These species reproduce and develop in streams or seeps, but transformed adults also occur in terrestrial habitats.

Width of riparian buffers explained 40% of the variance for total salamander abundance ($F_{1,16}$ = 11.748, P = 0.004, adjusted R^2 = 0.404) and 62% of the variance for amphibian species richness ($F_{1,16}$ = 27.206, $P \leq 0.001$, adjusted R^2= 0.621) at managed sites. Using the regression equation, we computed that buffer strips approximately 43 m wide would support total salamander abundance similar to that in average unlogged forests (Figure 1). Buffer strips approximately 47 m wide would support amphibian communities similar in species richness to that of average unlogged forests (Figure 1). The odds of detection increased in wider buffers for three of the four taxa we examined (Table 3). Similarly, the mean count of western red-backed salamanders increased in association with buffer strip width ($F_{1,16}$ = 9.144, P = 0.009).

The frequency of detections for most salamander species was found to exhibit either a significant positive or negative response to distance from the active channel (Figure 2). Three species were detected more frequently at quadrats nearest to the stream: Pacific giant salamanders (*Dicamptodon tenebrosus*) (χ^2 = 11.635, df = 3, P = 0.009), torrent salamanders (χ^2 = 7.462, df = 3, P = 0.059), and Dunn's salamander (χ^2 = 18.468, df = 3, P < 0.001). Two species were detected more frequently at quadrats further from the stream: ensatinas (χ^2 = 9.512, df = 3, P = 0.023) and clouded salamanders (χ^2 = 7.360 df = 3, P = 0.061). However, western red-backed salamanders did not exhibit any significant response to distance from stream (χ^2 = 2.328, df = 3, P = 0.507).

No species were found exclusively in unlogged forests or managed stands. Total salamander abundance, total amphibian species richness, and western red-backed salamander counts were greater in unlogged forests than managed stands (Table 4). Torrent salamanders and clouded salamanders had greater sampling probabilities in unlogged forests than managed stands (Table 5). However, we were unable to distinguish a difference in sampling probabilities between the two treatments for ensatina and Dunn's salamander.

Three attributes of live vegetation we measured were significantly different between buffers and unlogged riparian forests (Table 2). Unlogged forests had greater canopy closure, fern cover, and moss cover than did buffer strips. In addition, large-diameter log estimates (i.e., LOG60-99, LOG≥100) were substantially greater in unlogged riparian forest than buffer strips, but the differences were not proven statistically different. The failure to establish statistical difference is likely to be due more to high variance in log measurements among sites and low statistical power than a reflection of similar conditions (Table 2).

Table 3. Results of simple logistic regression analysis between buffer strip width and probability of occurrence in 17 managed stands in the Coast Range of Oregon surveyed during 1994–1995. *P*-values are the significance level for the effect of *Width* based on likelihood ratio tests.

Species	Intercept	Width term	95% CI width	P-value
Torrent salamanders (*Rhyacotriton varigatus, R. kezeri*)	–1.441	0.051	–0.005–0.126	0.036
Clouded salamander	–4.150	0.090	0.013–0.228	0.019
Ensatina	–0.307	0.031	–0.027–0.109	0.314
Dunn's salamander	–1.602	0.058	0.001–0.139	0.047

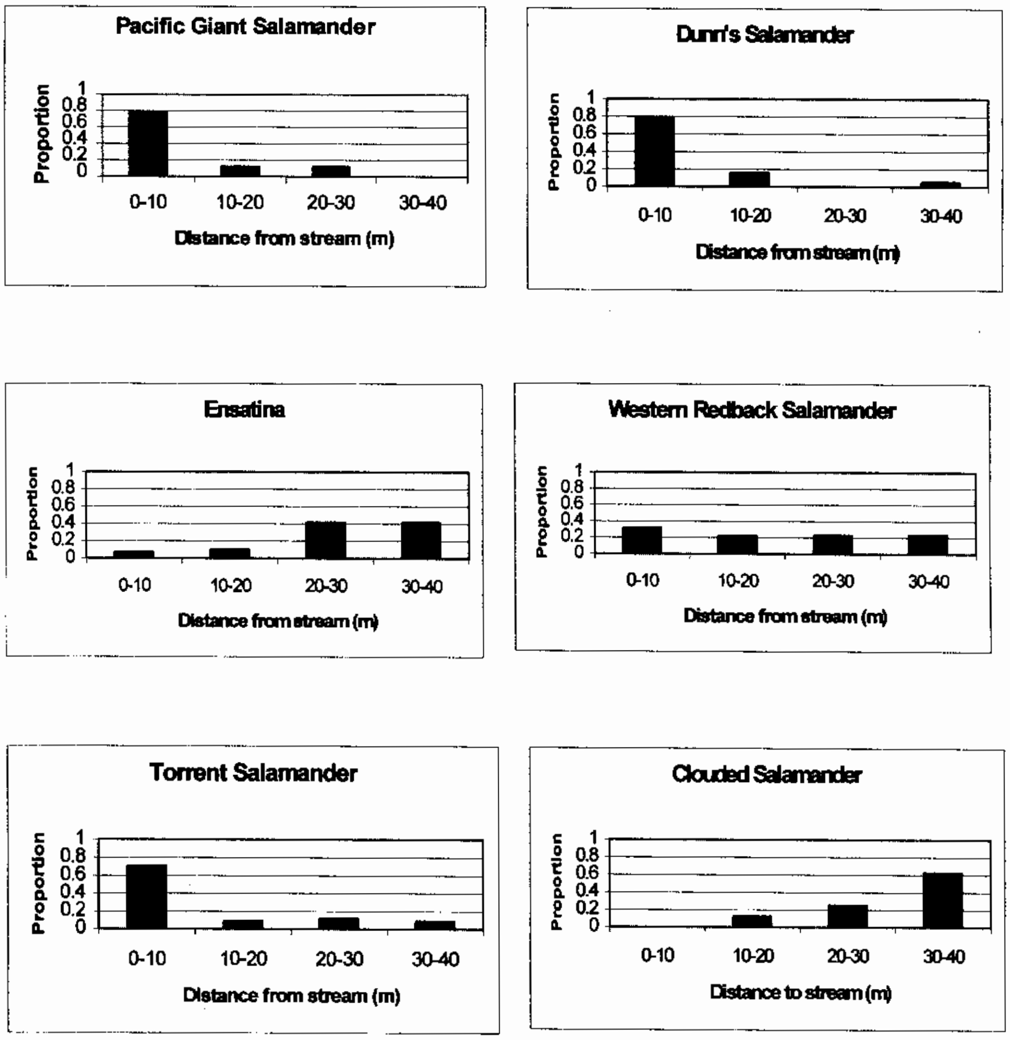

Figure 2. Frequency of detection in four distance-to-stream classes for six species of salamanders. Data are from 12 unlogged riparian forests in the Coast Range of Oregon surveyed during 1994–1995.

Discussion

Results of our survey supported our original hypothesis that salamander abundance and amphibian community diversity would exhibit a positive association with buffer strip width. Managed stands having buffers wide enough to completely contain sampling plots (i.e., buffer width ≥40 m) had only slightly lower salamander abundance than unlogged riparian forests. In contrast, managed sites that were clearcut supported about one-half the species richness and one-third the total abundance of salamanders in unlogged forests. Although we are not aware of other studies that have specifically examined terrestrial salamander populations in buffer strips, other amphibian-habitat relationship studies have demonstrated lower abundance or probability of occurrence in clearcuts than closed-canopy forests (Bury 1983, Corn and Bury 1989, Dupuis et al. 1995, Dupuis and Bunnell 1999, Ross et al. 2000).

Our examination of salamander distributions along a transriparian axis indicated that populations of Pacific giant salamanders, torrent salamanders, and Dunn's salamanders were most likely to benefit from buffer strips. These three species were found to be most closely associated with riparian areas at sites we surveyed. In contrast, ensatina and clouded salamander abundance increased at greater distances from the active channel, and western red-backed salamander abundance did not exhibit any gradient along the transriparian axis. Our results are generally

Table 4. Results of one-way analysis of variance to compare average counts for western red-backed salamander, total terrestrial salamander abundance, and amphibian species richness between riparian areas in 17 managed stands and 12 unlogged forests sites in the Coast Range of Oregon surveyed during 1994–1995.

	Mean (SE)		
Variable	Managed stands	Unlogged forests	*P*-value
W. red-backed salamander	14.7 (2.57)	22.4 (3.06)	0.066
Total salamander abundance	20.5 (3.39)	30.4 (4.04)	0.070
Amphibian species richness	3.3 (0.35)	4.8 (0.41)	0.008

Table 5. Results of Fisher's exact tests used to compare probability of terrestrial salamander occurrence between riparian areas in managed stands and unlogged forests in the Coast Range of Oregon surveyed during 1994–1995.

Species	No. individuals observed	Probability of occurrence: Managed stands (n = 17)	Unlogged forests (n = 12)	P-value
Torrent salamanders *(Rhyacotriton varigatus, R. kezeri)*	72	0.35	0.75	0.040
Clouded salamander	11	0.18	0.58	0.030
Ensatina	55	0.71	0.83	0.369
Dunn's salamander	36	0.41	0.67	0.165

consistent with those of two previous studies that compared amphibian populations in riparian and upslope habitats of the Oregon Coast Range. Gomez and Anthony (1996) found that capture rates of adult Pacific giant salamanders and Dunn's salamanders were greater at streamside transects than upslope transects (200 m from stream), but ensatinas were captured more frequently upslope. Gomez and Anthony (1996) also found that capture rates of western red-backed salamanders were not different between streamside and upslope transects. McComb et al. (1993) found that capture rates of total amphibians and Pacific giant salamanders were negatively correlated with distance from stream, but ensatina and western red-backed salamander abundance increased with distance from stream.

We conducted amphibian surveys in buffer strips less than 5 yr after the adjacent forest stand was clearcut. Although we did not examine long-term population responses in buffer strips and unlogged riparian forests, we did find that these types of stands differed in some vegetation attributes that may affect amphibian resistance. For example, measurements of large-diameter log (diameter >60 cm) abundance were twice as high in unlogged forests as it was in buffer strips. Comparison tests we performed did not show a statistically significant difference in log estimates, but this may be due to the high variability among sites and the low power of our study to detect such differences. We suggest that the failure to detect statistically significant differences in log abundance between buffers and unlogged forests does not detract from the biological importance of a reduction in coarse, woody debris availability to salamander populations. Evidence from previous studies indicates that decayed logs are an important habitat component for clouded salamanders, ensatinas, and western red-backed salamanders (Aubry et al. 1988, Dupuis et al. 1995).

Another potentially important difference to amphibians between buffers and unlogged forests was the degree of canopy closure. Canopy closure in buffers averaged only 65% of the level measured in unlogged forests. Our experience using spherical densiometers to measure canopy closure leads us to believe that the difference was due mainly to the clearcut opening next to the buffer, rather than a lower density of overstory trees within the buffer strip. Nevertheless, the adjacent clearcut may affect the microclimate within the buffer. Forest edges have been found to have higher wind velocities and greater diurnal variation in temperature and relative humidity than forest interiors (Chen et al. 1995). The influence of a clearcut edge extends >240 m into the forest interior for some environmental parameters (Chen et al. 1995). Plethodontid salamanders have a thin, permeable skin that makes them highly vulnerable to desiccation in dry environments (Feder 1983). Thus, the possibility cannot be dismissed that the combined effect of reduced canopy closure and lower availability of decayed logs may affect long-term persistence of salamander populations at buffers we surveyed.

Management Recommendations

Our findings lead us to conclude that minimum buffer requirements established by Oregon forest practice rules may not be sufficient to ensure that amphibian communities in managed stands remain as diverse as in unlogged forests. Minimum buffer strip widths required on most private forests in the state are only 6.1 m (20 ft) wide on medium streams (mean annual flow 0.28–0.06 m^3/sec; 10–2 ft^3/sec) that do not contain anadromous fish; no buffer strips are required on small, permanent streams (mean annual flow <0.6 m^3/sec; 2 ft^3/sec) (Oregon Department of Forestry 1997). In contrast to state forest practice rules, the BLM and USFS are establishing riparian reserves 79 m (260 ft) wide on permanent, nonfish bearing streams in Coast Range forests (Siuslaw National Forest 1995). It is estimated that federal riparian reserves will contain 80–90% of lands administered by the BLM and USFS in the Oregon Coast Range physiographic province (Siuslaw National Forest 1995). These extensive reserves are excluded from most forest management activities, except silviculture practices designed to accelerate development of late-successional forest characteristics (USDA and USDI 1994).

The results of this study and our review of other pertinent research lead us to make the following recommendations to managers wishing to increase the likelihood that terrestrial salamander populations will persist in forests they are managing:

1. Extend riparian buffer strip requirements on state and private lands to permanent headwater streams that are not necessarily inhabited by anadromous fish. These streams may be the highest quality breeding habitats for torrent salamanders, Pacific giant salamanders, and other amphibians.

2. Buffer strips 20 m wide contained approximately 80% of detectable torrent salamanders, Pacific giant salamanders, and Dunn's salamanders along first- through third-order streams that we surveyed. To ensure the availability of

breeding sites and hiding cover for these species in streams and streamside forests, logging practices that cause soil disturbance or decrease the abundance of downed logs should be avoided where salamander populations are concentrated. Buffer strips should be wide enough to ensure that riparian amphibian populations are protected against the high diurnal variation in temperature and relative humidity characteristic of clearcuts and forest edges. Perhaps riparian reserves could be designed in two parallel bands: a no-entry zone along the stream to protect amphibian microhabitats, and an adjoining limited-entry band designed to stabilize the riparian microclimate by utilizing a shelterwood system (Nyland 1996), rather than clearcutting. However, further research is needed to identify relationships between partial canopy removal and forest floor environment to ensure the effectiveness of such a strategy.

3. Finally, distributions of some terrestrial salamanders (i.e., ensatinas and clouded salamanders) are more closely associated with upland forests than riparian areas. Thus, buffer strips may not afford habitat protection for these populations. Alternative habitat conservation strategies may be necessary to maintain upland salamander populations on intensively managed private forests.

It is important to note that our study was based on an observational design that did not include a random selection procedure to ensure that our samples of managed and unlogged sites were strictly representative of riparian areas in the Oregon Coast Range. Thus, the scope of statistical inference for our study must be limited to sample of sites we visited. Nor did we demonstrate causal relationships between salamander abundance and buffer width or attributes of forest structure. We recommend that future studies monitor the survival and productivity of salamander populations to address the long-term effectiveness of buffer strips as an amphibian conservation strategy.

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