

Influence of Headwater Site Conditions and Riparian Buffers on Terrestrial Salamander Response to Forest Thinning

David E. Rundio and Deanna H. Olson

Abstract: Although thinning of young, even-aged forests may accelerate the development of characteristics associated with mature forests, in the short term it may negatively affect some taxa, including terrestrial salamanders. Preexisting site conditions, including down wood, and forest management measures, such as riparian buffers, may moderate these effects, but these relationships are poorly understood. To explore whether down wood and riparian buffer widths might influence short-term responses to thinning, we sampled salamanders using ground searches before and during the first 2 years after experimental thinning at two 45- to 65-year-old headwater forest sites in western Oregon that differed in down wood volume. Prethinning distributions of terrestrial salamanders overlapped one- and two-tree height riparian buffers, and except for red-backed salamanders, overlapped very little with narrower streamside or variable-width buffers. At the site where down wood volume was low, captures of ensatina (*Ensatina eschscholtzii* Gray) and western red-backed salamanders (*Plethodon vehiculum* Cooper) both declined by 40% in thinned areas. In contrast, captures of ensatina and Oregon slender salamanders (*Batrachoseps wrighti* Bishop) were not significantly affected by thinning at the site where down wood volume was high. Our results suggest that site conditions, such as down wood volume, and riparian buffers may influence the effect of thinning on terrestrial salamanders, and demonstrate the tight linkage among management of aquatic, riparian, and upslope resources in headwater forests. FOR. SCI. 53(2):320–330.

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FOREST THINNING is becoming an increasingly common management practice to increase structural diversity of young, even-aged stands and to promote the development of late-successional characteristics such as larger trees, multilevel canopies, and understory vegetation (Bailey and Tappeiner 1998, Busing and Garman 2002). These changes to stand conditions are expected to improve habitat quality for species associated with late-seral forests (Hayes et al. 1997), although the time frames for positive responses may vary by taxa. Some species of birds (Hayes et al. 2003, Hagar et al. 2004) and small mammals (Carey 2001, Suzuki and Hayes 2003) may respond almost immediately (within several years) to lowered tree density after thinning. In contrast, late-seral forest floor conditions may take much longer to develop, and there is concern that thinning may have negative short-term effects on certain ground-dwelling taxa in the interim (Wessell 2005).

Terrestrial salamanders appear to be a group that generally is vulnerable to negative short-term effects of thinning. Most forest salamanders require cool, moist microhabitats and are associated with late-seral conditions (Blaustein et al. 1995, deMaynadier and Hunter 1995, Welsh and Droege 2001). Thinning may reduce habitat quality for salamanders through direct disturbance to the forest floor during harvest (Grialou et al. 2000, Morneault et al. 2004) and by increasing temperature and reducing moisture from opening the

canopy (Anderson et al. 2007). Salamander abundance was reduced in the first 1 to 5 years after thinning in most previous experimental studies across a range of thinning intensities and forest types in North America (Harpole and Haas 1999, Grialou et al. 2000, Knapp et al. 2003, Morneault et al. 2004), and observational studies also have found that salamander abundance was lower in thinned stands compared with unthinned stands (Naughton et al. 2000, Brooks 2001). However, several studies have shown either no difference or higher abundance in thinned stands, as well as variable responses among species (Suzuki 2000, Bartman et al. 2001, MacCracken 2005, Karraker and Welsh 2006). These different results between studies in similar stand types in the same region (cf. Grialou et al. 2000, Suzuki 2000) and variable responses between species suggest that local factors, such as site conditions, may interact with species-specific habitat associations to influence the effects of thinning. Differences in forest floor conditions have been shown to mediate the effects of thinning on ground-dwelling arthropods (Schowalter et al. 2003), but these relationships have not been addressed for salamanders despite their strong habitat associations with forest floor conditions such as down wood and other cover objects (Blaustein et al. 1995, Grover 1998, Butts and McComb 2000) that may moderate the effects of microclimate changes in the stand after thinning.

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Although forest floor conditions may determine, at least in part, the effect of thinning on terrestrial salamanders within stands, the presence of adjacent unthinned stands also may be important for the resilience of populations across the landscape in the event of negative short-term effects. In regions such as the US Pacific Northwest, where forests are highly dissected by streams (especially small headwater streams), riparian buffers often are the most widespread and extensive unharvested areas (USDA and USDI 1994). In headwaters, streams and adjacent hillslopes are tightly linked through physical and biological conditions and processes involving water, sediment, nutrients and organic matter, and organisms (Gomi et al. 2002), yet the interactions among these areas are not fully understood under undisturbed conditions, let alone with forest management activities potentially disrupting natural processes. In particular, under current management practices in the Pacific Northwest, while riparian buffers and thinning often are applied adjacently within forest stands, questions remain about how terrestrial wildlife respond to these practices when they are applied in conjunction (Olson et al. 2002). Distributions of amphibian species appear to be strongly associated with different geomorphic zones in headwaters in unmanaged forests where riparian areas are spatially compressed (Sheridan and Olson 2003), and narrow headwater streamside zones may provide critical ecological functions only for stream- and bank-associated amphibians. Therefore, while headwater riparian buffers may offer refugia or dispersal corridors for amphibians until favorable conditions develop in thinned stands, these benefits may be largely limited to aquatic and riparian species and may not apply to terrestrial species with upslope distributions (Vesely and McComb 2002, Petranksa and Smith 2005).

Our objectives were to determine the short-term effects of forest thinning on terrestrial salamanders in managed headwater forests in western Oregon, and to explore the potential for site conditions and riparian buffers to influence these effects. We selected two sites that represented low and high down wood volumes from the region as independent case studies to evaluate salamander responses to experimental thinning, and compared the distributions of salamanders relative to distance from streams with the widths of different riparian buffers currently used in the region.

Methods

Study Area

We conducted our study at two headwater forest sites in western Oregon, one in the Coast Range (Green Peak: N44°22'00", W123°27'30") and the other in the Cascade Range (Keel Mountain: N44°31'41", W122°37'55"), that are part of the US Bureau of Land Management (BLM) Density Management and Riparian Buffer Study (Cissel et al. 2006; see also Anderson et al. 2007, Olson and Weaver 2007, Olson and Rugger 2007). Both sites contained 45- to 65-year-old stands managed by the BLM, and are in the western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) vegetation zone (Franklin and Dyrness, 1988). Douglas-fir (*Pseudotsuga menziesii* [Mirbel] Franco) was the dominant overstory tree at the Coast Range site, whereas Douglas-fir

and western hemlock were co-dominant species at the Cascade Range site. Other trees at the sites included western redcedar (*Thuja plicata* Donn.) and red alder (*Alnus rubra* Bong.). The most common understory vegetation was western swordfern (*Polystichum munitum* [Kaulfuss] K. Presl), Oregon grape (*Berberis nervosa* Pursh), salal (*Gaultheria shallon* Pursh), red huckleberry (*Vaccinium parvifolium* Sm.), vine maple (*Acer circinatum* Pursh), and Oregon oxalis (*Oxalis oregano* Nutt.). Moss and litter were the main ground covers. Both of these headwater sites are drained by a dense network of small, intermittent and perennial streams. Elevation is about 500 to 750 m at the Coast Range site and about 600 to 750 m at the Cascade Range site (Cissel et al. 2006). Climate is moderate at these elevations in western Oregon, and precipitation occurs primarily as rain during fall through spring, with dry summers. Mean temperatures are similar between sites, although mean annual rainfall is estimated to be greater at the Coast Range site (171 cm yr⁻¹) than at the Cascade Range site (126 cm yr⁻¹; Anderson et al. 2007). The Coast Range site is on north and east aspects, with slope steepness distributed about equally in both the 0–30% and 30–60% ranges, while the Cascade Range site is on south and west aspects, with slope steepness only in the 0–30% range (Cissel et al. 2006).

Forest floor conditions differed between the two sites as a legacy of past land management activities. The Coast Range site was clearcut logged and burned in the mid-1930s, and livestock were grazed for several years before trees regenerated. As a result, the volume of down wood on the forest floor was low and primarily in early stages of decay (150 m⁻³ ha⁻¹, S. Chan, unpublished data; Olson et al. 2006). In contrast, the Cascade Range site was clearcut in the late 1940s, but selective removal of felled trees left a high volume of down wood that is now in moderate and late stages of decay (750 m⁻³ ha⁻¹, S. Chan, unpublished data; Olson et al. 2006). For comparison, Butts and McComb (2000) reported a range of down wood of 14 to 859 m⁻³ ha⁻¹ from young (23–67 years), low-elevation stands in western Oregon.

Experimental Design

Our study was part of the larger Density Management and Riparian Buffer Study examining the effects of different thinning intensities and riparian buffer widths on aquatic and streambank vertebrates in headwater forests at many sites in western Oregon (Olson et al. 2002, Cissel et al. 2006, Olson and Rugger 2007, Olson and Weaver 2007). For this component, we took advantage of the existing experimental design and manipulations to additionally focus on the responses of terrestrial amphibians to moderate levels of thinning (target density of 200 trees ha⁻¹) in relation to riparian buffers of different widths. For the larger study, sites were selected nonrandomly for young stands of relatively homogenous structure in low-elevation federal forest lands in western Oregon (Cissel et al. 2006); we selected two sites from the larger study that represented low and high down wood volumes from the region as independent case studies to explore the effects of down wood on salamander

responses to thinning. At each site, moderately thinned and unthinned reference units (18–46 ha) were assigned nonrandomly according to operational constraints, such as road and stream locations. Within the moderately thinned units, riparian buffer treatments also were assigned nonrandomly according to operational constraints, such as the distance from stream to ridgeline, so that both a buffer and thinned matrix could be implemented before crossing into the neighboring subdrainage (Figure 1).

The four riparian buffer treatments represented a range of widths corresponding to current federal and state forestry practices. One and two site-potential tree height buffers (minimum 70 and 145 m slope distance, respectively) are the current interim guidelines under the federal Northwest Forest Plan for fishless and fish-bearing streams, respectively (USDA and USDI 1994). Variable-width buffers (minimum 15 m) were delineated according to site-specific local boundaries between riparian and upslope topography and vegetation, and are relevant to state forestry practices. Streamside buffers (minimum 6 m) retained the first streamside tree to provide bank stability and stream shading. The two-tree height treatment was not included at the Coast Range site because there were not enough streams for all treatments. Each buffer treatment extended a minimum of 110 to 150 m along streams (i.e., stream length).

The moderate thinning prescription was intended to promote stand diversity and heterogeneity, hence thinning was not uniform across the stands. Approximately 80% of the area of the stands was thinned, 10% was cut in dispersed 0.1–0.4 ha patch openings, and 10% was unthinned in dispersed 0.1–0.4 ha leave islands. Leave islands were located to mitigate concerns for sensitive wildlife, invertebrates, and plant species. In addition, large or rare conifers, hardwoods, small understory trees (<12 cm dbh), snags, and down wood were retained during thinning. Trees were

manually thinned from below, and felled trees were removed using skyline cable yarding at the Coast Range site and ground-based yarding at the Cascade Range site. At the Coast Range site, stands were thinned from 320 trees ha⁻¹ to a target of 200 trees ha⁻¹; in comparison, the unthinned reference stand had 410 trees ha⁻¹. At the Cascade Range site, stands were thinned from 560 trees ha⁻¹ to a target of 240 trees ha⁻¹, and the reference stand had 560 trees ha⁻¹. At both sites, average canopy closure was about 80% before and no less than 40% after thinning.

Amphibian Sampling

We sampled terrestrial amphibians along trans-riparian transects that began at the stream edge and extended uphill, perpendicular to the stream, through the riparian area and into the upslope forest (Figure 1). Transects were nonrandomly located near the center of the riparian reserve treatments to avoid edge effects due to neighboring treatments, in areas of relatively uniform topography from stream to ridge, and away from patch openings and leave islands. Each transect consisted of four 2 m-wide parallel lines arrayed within 15 m either side of transect center to increase the spatial coverage of sampling in light of the patchy distributions of salamanders; line locations were staggered by year to avoid sampling the same location twice. At the Coast Range site, we sampled two transects, on opposite sides of a stream, per riparian buffer treatment (three buffer widths and reference), for a total of eight transects. At the Cascade Range site, we sampled two transects in the streamside retention and reference treatments, but only one transect in each of the variable-width one-tree and two-tree treatments, for a total of seven transects. Transect lengths varied according to constraints such as the distance from stream to ridge and road locations. At the Coast Range site, average transect length was 102 m (range = 60–142 m) and total sample area was 6,512 m². At the Cascade Range site, average length was 112 m (range = 60–200 m) and sample area was 6,264 m².

We used garden claws to search for amphibians in and under all ground cover, down to soil, along the entire length of each transect. Cover objects such as logs, moss, rocks, and litter were searched systematically from the surface through underlying layers, which were separated to expose interstitial spaces; decayed logs were opened as much as possible using hands and garden claws. Cover objects were carefully replaced after searching to reduce habitat disturbance. For each amphibian capture, we recorded species, distance to stream, cover object, and substrate at capture site. We sampled each site three times, 1 year before and in the 2 years after thinning. The Cascade Range site was sampled in 1997 (prethinning) and 1999–2000 (postthinning), and the Coast Range site was sampled in 1998 (prethinning) and 2000–2001 (postthinning). All sampling was done in May–June during the spring rainy season, when surface activity by amphibians is greatest in the Pacific Northwest (Ovaska and Gregory 1989, Dupuis et al. 1995).

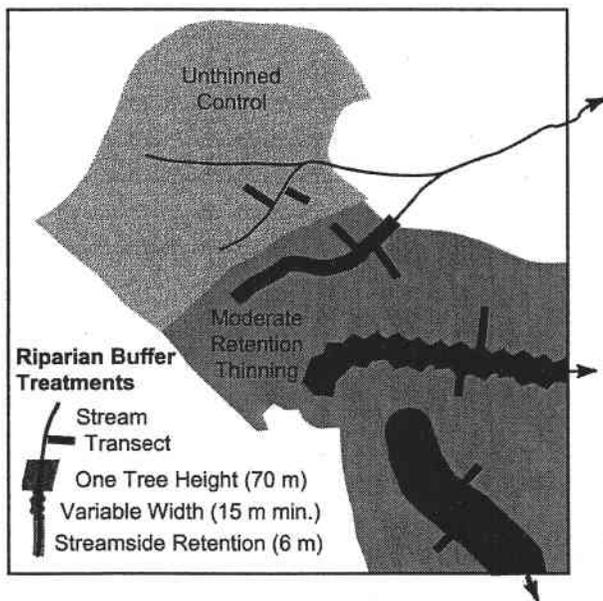


Figure 1. Map of the Oregon Coast Range study site showing locations of reference and thinned stands, streams, riparian buffers, and sampling transects.

Data Analysis

To test whether thinning affected amphibian captures, we compared the change in captures before and after thinning in thinned upslope areas with the change in captures in unthinned areas within riparian buffers, and analyzed each site separately due to the case study design. Because transects spanned adjacent unthinned and thinned areas, we paired the data for the thinned and unthinned portions of each transect and used paired *t*-tests (Sokal and Rohlf 1995). We also used paired *t*-tests to assess whether captures in the reference transects differed between the pre and postthinning sampling periods as a reference for temporal variation in amphibian captures in untreated stands, to aid interpretation of results from the thinned stands. Kolmogorov-Smirnov tests and visual inspection indicated that the data met the assumption of normality. We calculated captures m^{-2} to account for differences in transect length and sample area, and used the average of the two postthinning samples in statistical tests. We tested for thinning effects separately for all species with ≥ 30 captures. We used $P < 0.10$ to indicate statistical significance to balance type I and type II errors associated with small sample size (Toft and Shea 1983, Vesely and McComb 2002, Suzuki and Hayes 2003, Hagar et al. 2004). Despite our collection of pretreatment, posttreatment, and reference data, analysis of variance

(ANOVA), before-after-control-impact (BACI), or split-plot analysis approaches were not used due to the limitations of our design and data, including the large differences of pretreatment captures among transects that might cloud potential treatment effects, small sample sizes, lack of independence of samples collected along transects, and nonrandom study site selection, treatment assignments, and sampling locations.

We used pretreatment capture data to assess the extent of overlap between the distributions of terrestrial salamanders and the different riparian buffer widths to be implemented. To determine the distributions of species with respect to distance from stream, we averaged captures m^{-2} in 10-m intervals from the stream from all transects at a site. Inferences from our analyses are limited to the specific conditions at each of these sites as independent case studies, due to our nonrandom site selection, treatment designation, and transect locations.

Results

We recovered a total of 1,150 captures from 10 species of amphibians during 3 years of sampling at both sites (Table 1). Amphibian captures varied considerably among transects within sites (spatially) and among years within

Table 1. Total captures of amphibians at the two study sites in western Oregon

Species	No. Captures			Total
	Pretreatment	Posttreatment		
COAST RANGE year	1998	2000	2001	
Western red-backed salamander	100	123	95	318
<i>Plethodon vehiculum</i> Cooper				
Ensatina	83	72	50	205
<i>Ensatina eschscholtzii</i> Gray				
Rough-skinned newt	11	7	6	24
<i>Taricha granulosa</i> Skilton				
Dunn's salamander	1	14	7	22
<i>Plethodon dunni</i> Bishop				
Coastal giant salamander	3	1	3	7
<i>Dicamptodon tenebrosus</i> Baird and Girard				
Southern torrent salamander	0	3	2	5
<i>Rhyacotriton variegatus</i> Stebbins and Lowe				
Coastal tailed frog	2	2	1	5
<i>Ascaphus truei</i> Stejneger				
Northwestern salamander	1	1	1	3
<i>Ambystoma gracile</i> Baird				
Total	201	223	165	589
CASCADE RANGE year	1997	1999	2000	Total
Ensatina	104	95	132	331
<i>Ensatina eschscholtzii</i>				
Oregon slender salamander	80	46	68	194
<i>Batrachoseps wrighti</i> Bishop				
Coastal giant salamander	7	5	2	14
<i>Dicamptodon tenebrosus</i> Baird and Girard				
Cascade torrent salamander	1	2	7	10
<i>Rhyacotriton cascadae</i> Good and Wake				
Dunn's salamander	3	2	1	6
<i>Plethodon dunni</i> Bishop				
Northwestern salamander	0	3	2	5
<i>Ambystoma gracile</i> Baird				
Rough-skinned newt	0	1	0	1
<i>Taricha granulosa</i> Skilton				
Total	195	154	212	561

transects (temporally; Figure 2). Pretreatment captures averaged 0.3 m^{-2} at both sites. Western red-backed salamander (*Plethodon vehiculum* Cooper; 54% of total

captures) and ensatina (*Ensatina eschscholtzii* Gray; 35%) accounted for the majority of captures at the Coast Range site, whereas ensatina (59%) and Oregon slender

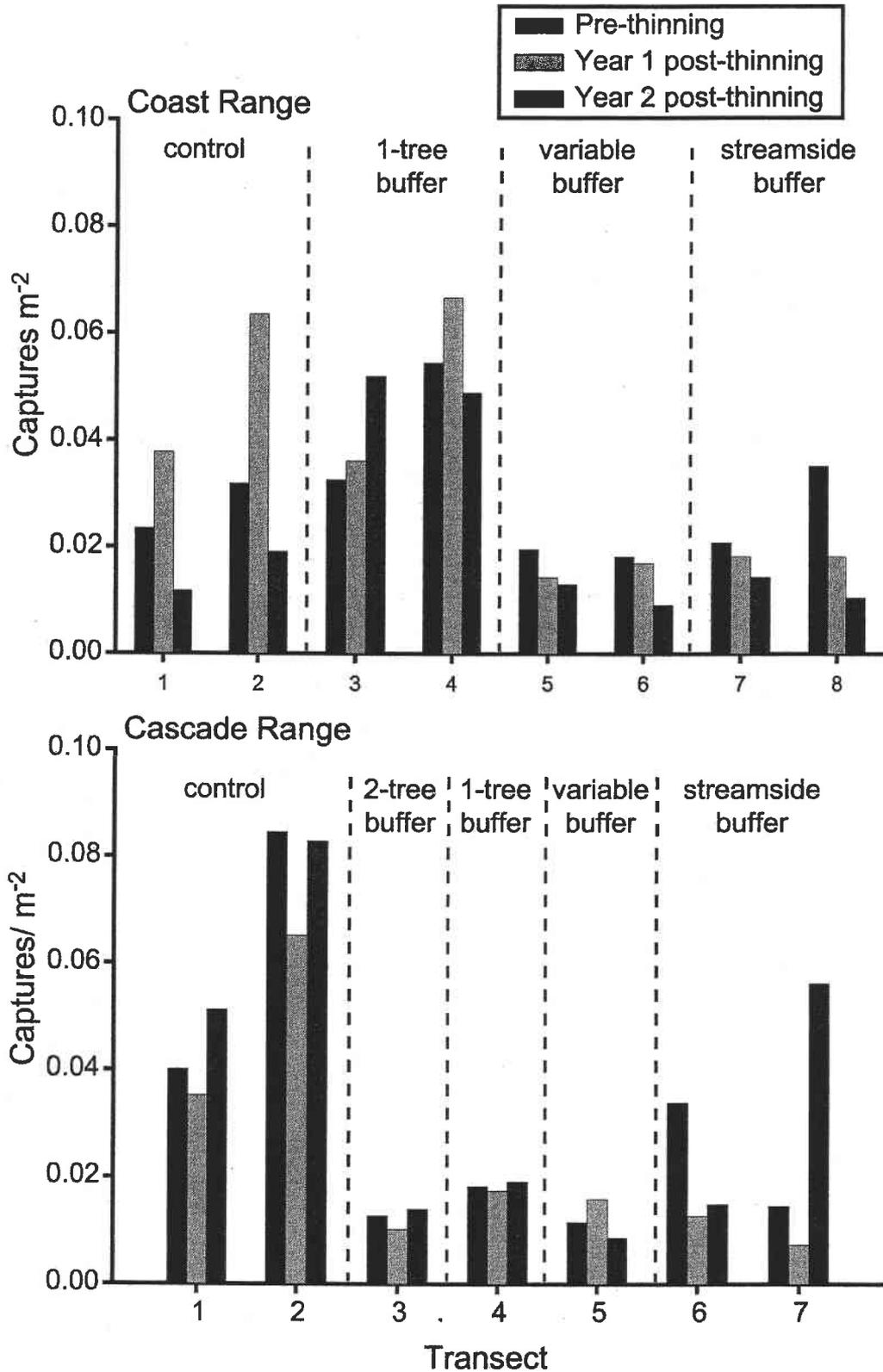


Figure 2. Total amphibian captures at the two western Oregon study sites by transect and year. Transects are grouped by treatment type, indicated above bars. Captures in thinned and unthinned portions of transects are combined.

salamander (*Batrachoseps wrighti* Bishop; 35%) dominated captures at the Cascade Range site (Table 1).

Spatial Distribution with Respect to Riparian Buffers

Pretreatment captures of terrestrial salamanders varied considerably among 10-m distance intervals from the stream, but at both sites generally were highest 100 to 130 m

from the stream (Figure 3). Overlap between salamander distributions and riparian buffers was greater at the Cascade Range site than at the Coast Range site. At the Cascade Range site, the highest captures of ensatina and Oregon slender salamanders occurred within areas that would be included in two-tree height buffers, captures were moderately high within one-tree buffers, and captures were low within variable-width and streamside-retention buffers (Figure 3). At the Coast Range site, ensatina captures were

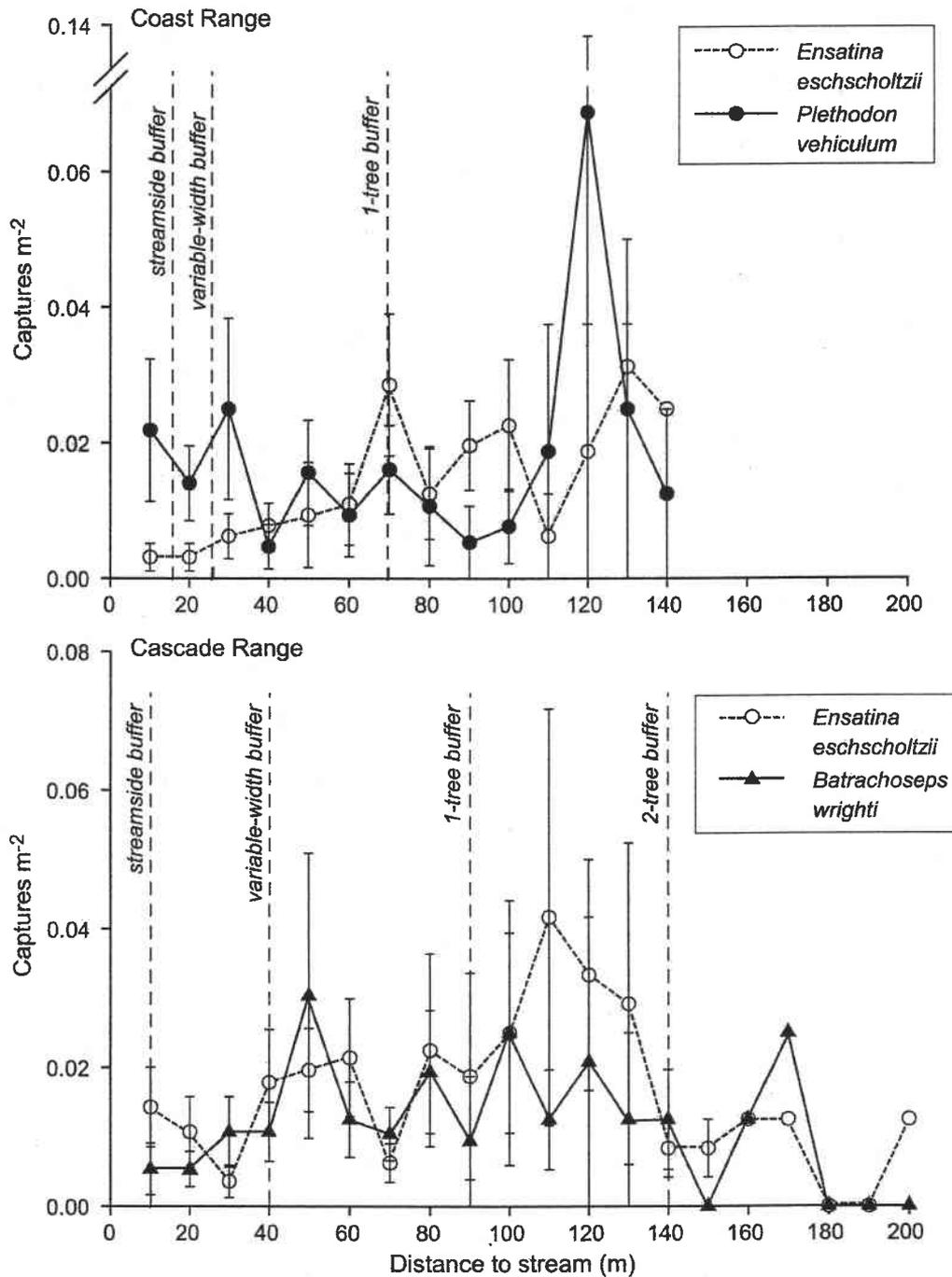


Figure 3. Distribution of *Plethodon vehiculum*, *Ensatina eschscholtzii*, and *Batrachoseps wrighti* with respect to distance from stream and widths of riparian buffer types. Data are mean captures (\pm SE) from all transects from prethinning surveys in 10-m intervals starting from the stream and extending upslope.

highest ≥ 70 m from the stream, and were low in areas that would be included in any of the buffer types at this site (Figure 3). Captures of western red-backed salamanders also were highest outside of riparian buffers, although they were relatively more abundant than ensatina within the narrower buffers, extending 0 to 30 m from the stream (Figure 3).

Effects of Thinning

At the Coast Range site, average posttreatment captures of ensatina decreased 42% from pretreatment captures in thinned areas but did not decline in unthinned riparian buffers ($P = 0.05$; Figure 4). Captures of western red-backed salamanders decreased 40%, on average, in thinned areas and increased 50% in riparian buffers ($P = 0.08$; Figure 4). In contrast, changes in captures of ensatina and Oregon slender salamanders did not differ between thinned and unthinned areas at the Cascade Range site (ensatina: $P = 0.35$; slender salamander: $P = 0.42$; Figure 4). At both sites, captures within reference stands did not differ between pre and postthinning sampling periods for any species (Coast Range site: ensatina, $P = 0.75$, red-backed salamander, $P = 0.97$; Cascade Range site: ensatina, $P = 0.35$, slender salamander, $P = 0.47$; Figure 4).

Cover Object Use

Cover use by salamanders differed between the two sites, and, at the Coast Range site, between species (Figure 5). At the Coast Range site, more salamanders were captured under litter and moss than were captured under wood. Ensatina captures were relatively equally distributed among litter, moss, and wood, whereas 50 to 60% of western red-backed salamanders were captured under moss and 15 to 20% were captured under litter or wood (Figure 5). In contrast, at the Cascade Range site, most ensatina (75–85%) and Oregon slender salamanders (80–95%) were captured under wood, and litter and moss accounted for a minority of captures (Figure 5). Cover object use did not appear to be affected by thinning.

Discussion

The short-term effect of moderate forest thinning on terrestrial salamanders in managed 45- to 65-year-old headwater forests differed between our two sites in western Oregon. At the Coast Range site, captures of ensatina and western red-backed salamanders decreased in thinned stands relative to adjacent unthinned riparian buffers. In contrast, thinning did not affect captures of ensatina and Oregon slender salamanders at the Cascade Range site. These sites were selected for the BLM Density Management

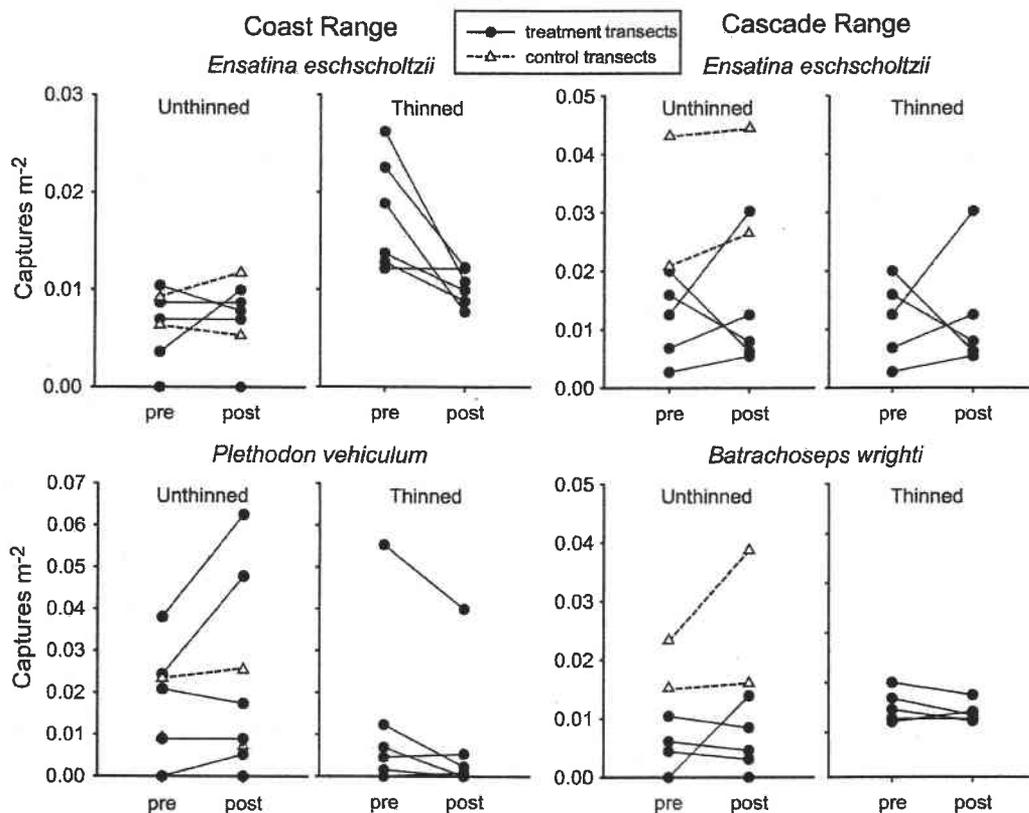


Figure 4. Salamander captures by transect before and after thinning in thinned and unthinned areas. Unthinned areas include reference transects and riparian buffers within treatment transects. Thinned areas are treatment transects upslope of riparian buffers. Postthinning values are means from sampling 1 and 2 years after thinning. Note that y axis scaling varies among plots.

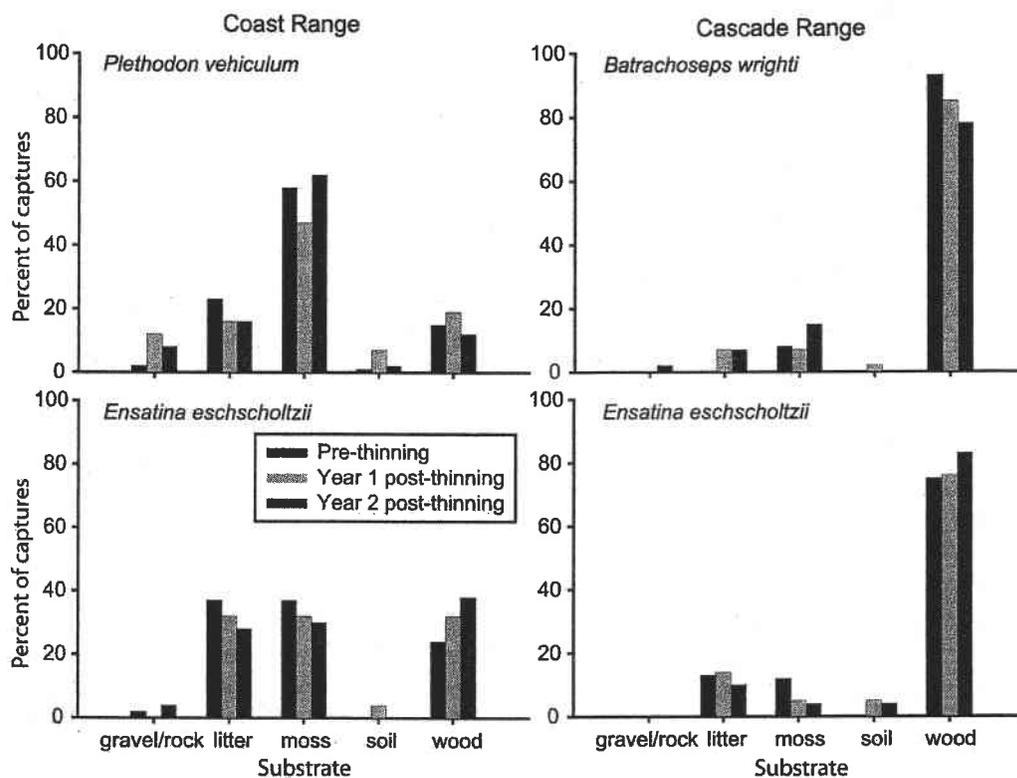


Figure 5. Cover object use by *Plethodon vehiculum*, *Ensatina eschscholtzii*, and *Batrachoseps wrighti*. Use is shown as the percentage of captures under different cover types, with captures summed across all transects.

and Riparian Buffer Study from stands with generally similar forest types and management histories (Cissel et al. 2006), although they differed from one another in a number of ways (e.g., dominant overstory tree species and initial density, precipitation, certain aspects of past management, aspect and slope steepness, and volume of down wood; see Methods). Considering known terrestrial salamander habitat associations, down wood volume was the single most striking of these differences between the sites, although we cannot rule out the potential interacting roles of other factors such as precipitation, aspect and slope steepness (or their interaction, such as hill-shading), or other differences associated with the two ecoregions represented by the sites, the Oregon Cascades and Coast Ranges. Hence, the decline of salamander captures after thinning at the Coast Range site where down wood volume was low but not at the Cascade Range site, where wood volume was high, suggests that site features such as down wood may have moderated the effects of thinning on salamanders. Although forest floor conditions have been shown to influence the effect of thinning on ground-dwelling arthropods (Schowalter et al. 2003), our study is the first to suggest that preexisting site conditions such as down wood volume may mediate responses to forest thinning by terrestrial salamanders. This may account for differences in the effects of thinning observed in previous studies (e.g., cf. Grialou et al. 2000, Suzuki 2000), although differences in the way down wood volume and other habitat conditions were reported (i.e., percentage ground cover versus cumulative length or frequency of logs) make studies difficult to compare. The role

of preexisting site conditions warrants further consideration in forest management studies and designs when ground-dwelling species protection is identified as a priority.

The potential for riparian buffers to act as refugia to benefit terrestrial salamanders during thinning in these headwater forests appears to depend on both the distributions of different species and site conditions that dictate buffer widths. While captures of all three of the dominant species generally were highest in the upslope forest 100 to 130 m from the stream, western red-backed salamanders also were relatively abundant in the riparian zone near the stream. These patterns are consistent with previous studies showing that ensatina are associated mostly with upslope areas and western red-backed salamanders are more evenly distributed from streamside to upslope (McComb et al. 1993, Gomez and Anthony 1996, Vesely and McComb 2002, Sheridan and Olson 2003).

When these distributions are compared with different buffer widths, it generally appears that streamside and variable-width buffers will provide poor coverage for populations of all three species, and especially ensatina and Oregon slender salamanders, similar to the conclusions of Vesely and McComb (2002). Petranka and Smith (2005) suggested that even narrow buffers such as these might provide sources for populations to recolonize harvested upslope areas, although studies are needed to evaluate this idea. Alternatively, retained riparian corridors might facilitate dispersal from adjacent undisturbed stands. One-tree height buffers, prescribed on federal lands as an interim buffer width along fishless streams, appear to be wide enough to

include areas where all three species occur in some abundance, but fall short of the areas of highest abundance. However, they seem more likely than the narrower buffers to shelter enough of the populations to provide a source for recolonization. Two-tree height buffers, applied as an interim width to protect fish-bearing streams on federal lands, encompassed the upslope areas where ensatina and Oregon slender salamanders were most abundant at the Cascade Range site. In general, it appears that additional protections may be warranted in fishless headwater streams where narrow buffers may not mitigate concerns about negative effects of thinning on terrestrial salamanders.

Cover object use by salamanders in our study sites was consistent with the literature. Western red-backed salamanders used a variety of cover objects including logs, wood, moss, litter, and gravel/rock, similar to populations in Washington (Dupuis et al. 1995) and British Columbia (Ovaska and Gregory 1989), although a higher proportion were captured under moss than in the other studies. Ensatina and Oregon slender salamanders were strongly associated with down wood at the Cascade Range site where it was abundant, as has been widely documented (Blaustein et al. 1995, Butts and McComb 2000, Biek et al. 2002). However, cover use by ensatina appears to be flexible, depending on the availability of down wood. At the Coast Range site where down wood volume was low, ensatina were captured equally under litter, moss, and wood. The diversity of cover use by ensatina and western red-backed salamanders may contribute to explanations for why they are relatively more widespread in distribution compared to other plethodontids in the Pacific Northwest (Jones et al. 2005). Their microhabitat diversity also may explain their relative apparent resiliency to forest management in the region; they are not included on United States state or federal lists of sensitive species that are vulnerable to anthropogenic disturbances (e.g., Corkran and Thoms 2006). However, although these salamanders can exploit a variety of cover types, postthinning declines in captures at the Coast Range site but not at the Cascades Range site suggest that cover types may differ in how they influence salamander responses to thinning, with down wood appearing to buffer responses more than litter or moss.

Several cautions are required for interpreting our results. We detected changes in captures of salamanders from ground searches before and after thinning at the Coast Range site, but it is unclear to what extent these changes reflect changes in population size, changes in surface activity and detection rate, or emigration (deMaynadier and Hunter 1995). Surface counts often are highly correlated with population size (Petranka et al. 1993, Smith and Petranka 2000, Bailey et al. 2004b, but see Dodd and Dorazio 2004), and are widely used to assess responses of amphibians to forestry practices (deMaynadier and Hunter 1995). However, studies from the eastern United States have found that surface activity and detection rates of terrestrial salamanders are highly variable in time and space and among species, and may be influenced by environmental conditions such as forest type, management history, and elevation (Hyde and Simons 2001, Bailey et al. 2004a, b, Dodd and Dorazio 2004) in ways that confound the rela-

tionship between counts and population size. These studies suggest that surface activity and detection rate may be affected by forest management, although none has compared detection rates before and after management to test whether detectability changed. Marsh and Beckman (2004) did not detect differences in detection rates of eastern red-backed salamanders (*Plethodon cinereus* Green) between experimental enclosures in forest edge and interior habitats. We conducted surveys during the spring rainy season when surface activity of terrestrial salamanders in Pacific Northwest forests is high (Ovaska and Gregory 1989, Dupuis et al. 1995) to reduce variability in surface activity, but we cannot determine whether activity and detection rate differed before and after thinning.

We also cannot determine whether emigration contributed to the changes in captures we observed from thinned transects at the Coast Range site. Movement studies have found that ensatina and western red-backed salamanders have small home ranges and on average move only short distances (i.e., less than 10 m; Ovaska 1988, Maxcy and Richardson 2000, Karraker and Welsh 2006), suggesting that emigration might have been very limited. Furthermore, Bartman et al. (2001) did not detect emigration of Jordan's salamanders (*Plethodon jordani* Blatchley) using mark-recapture methods from experimentally thinned stands in North Carolina. However, examples of large-scale movement by terrestrial salamanders have been observed (deMaynadier and Hunter 1995), so emigration cannot be ruled out. Future experiments replicated across a range of stand conditions, or manipulating conditions such as down wood directly, and using mark-recapture methods (e.g., Bartman et al. 2001), are needed to more directly test the effect of stand conditions on salamander responses to thinning and to assess the extent to which changes in captures we and other studies detected after thinning are due to changes in population size, reduced surface activity, or movement.

While these limitations prevent us from determining the mechanisms involved, salamander responses to thinning—whether population size, surface activity, or emigration—nevertheless differed between the Coast Range and Cascade Range sites. Reduced surface activity and local emigration over time may affect population size by lowering growth, survival, or reproduction, although these relationships are poorly understood. Karraker and Welsh (2006) found that body condition index (i.e., weight-length ratio) of ensatina was 10% higher in unthinned stands than in stands thinned more than 10 years before sampling in northern California; the cause was unclear, but lower condition may reduce fecundity and survival. Survival of salamanders that emigrate from a site is unknown (deMaynadier and Hunter 1995), although Petranka (1994) argued that survival probably is very low due to territoriality and physiological stress. Although these potential effects are speculative with respect to our results, they indicate that differences between sites in surface activity or emigration may have consequences for salamander populations.

In conclusion, our results, while exploratory and representing case study sites in two ecoregions, suggest that site conditions such as volume of down wood may determine the short-term responses of terrestrial salamanders to forest

thinning, and hence could be considered in designing management strategies to ameliorate adverse effects on target species. For example, in young stands where down wood is abundant and terrestrial salamanders are a concern, managers may be able to thin forests more intensively to accelerate the development of late-seral conditions. Also, in those stands, riparian reserves may be considered sufficient to provide refuge for a portion of the population. However, in stands with little down wood, riparian buffer width would need consideration, and additional protections such as unthinned leave islands (Wessell 2005) may help minimize negative effects of thinning on salamanders and other ground-dwelling taxa, especially in fishless headwaters where the narrowest riparian buffers may be proposed. It should be noted, however, that although we documented decreases in terrestrial salamander captures postthinning at the Coast Range site, these taxa were not eliminated from the thinned area. Thus, they persisted at sites postdisturbance, which may be consistent with management objectives (i.e., to reduce risk of local extinction while managing stands for other objectives, such as commodity production or restoration). Nonetheless, management to provide for the long-term recruitment of down wood to the forest floor should increase management flexibility with regard to concern for the persistence of terrestrial salamanders. Finally, our study demonstrates the tight linkage between management of aquatic, riparian, and upslope resources in headwater forests and the potential interplay of multiple management approaches.

Literature Cited

- ANDERSON, P.D., D.J. LARSON, AND S.S. CHAN. 2007. Riparian buffer and density management influences on microclimate of young headwater forests of western Oregon. *For. Sci.* 53:254–269.
- BAILEY, L.L., T.R. SIMONS, AND K.H. POLLOCK. 2004a. Estimating site occupancy and species detection probability parameters for terrestrial salamanders. *Ecol. Applic.* 14:692–702.
- BAILEY, L.L., T.R. SIMONS, AND K.H. POLLOCK. 2004b. Spatial and temporal variation in detection probability of *Plethodon* salamanders using the robust capture-recapture design. *J. Wildl. Manag.* 68:14–24.
- BAILEY, J.D., AND J.C. TAPPEINER. 1998. Effects of thinning on structural development in 40- to 100-year-old Douglas-fir stands in western Oregon. *For. Ecol. Manag.* 108:99–113.
- BARTMAN, C.E., K.C. PARKER, J. LAERM, AND T.S. MCCAY. 2001. Short-term response of Jordan's salamander to a shelterwood timber harvest in western North Carolina. *Phys. Geogr.* 22:154–166.
- BIEK, R., L.S. MILLS, AND R.B. BURY. 2002. Terrestrial and stream amphibians across clearcut-forest interfaces in the Siskiyou Mountains, Oregon. *Northwest Sci.* 76:129–140.
- BLAUSTEIN, A.R., J.J. BEATTY, D.H. OLSON, AND R.M. STORM. 1995. *The biology of amphibians and reptiles in old-growth forests in the Pacific Northwest*. USDA For. Serv. Gen. Tech. Rep. PNW-GTR-337. 98 p.
- BROOKS, R.T. 2001. Effects of the removal of overstory hemlock from hemlock-dominated forests on eastern redback salamanders. *For. Ecol. Manag.* 149:197–204.
- BUSING, R.T., AND S.L. GARMAN. 2002. Promoting old-growth characteristics and long-term wood production in Douglas-fir forests. *For. Ecol. Manag.* 160:161–175.
- BUTTS, S.R., AND W.C. MCCOMB. 2000. Associations of forest-floor vertebrates with coarse woody debris in managed forests of western Oregon. *J. Wildl. Manag.* 64:95–104.
- CAREY, A.B. 2001. Experimental manipulation of spatial heterogeneity in Douglas-fir forests: Effects on squirrels. *For. Ecol. Manag.* 152:13–30.
- CISSEL, J.H., P.D. ANDERSON, D. OLSON, K. PUETTSMANN, S. BERERYMAN, S. CHAN, AND C. THOMPSON. 2006. *BLM density management and Riparian Buffer Study: Establishment report and study plan*. US Geological Survey, Scientific Investigations Report 2006-5087. 151 p.
- CORKRAN, C.C., AND C. THOMS. 2006. *Amphibians of Oregon, Washington and British Columbia*. Lone Pine Publ., Auburn, WA.
- DEMAYNADIER, P.G., AND M.L. HUNTER JR. 1995. The relationship between forest management and amphibian ecology: A review of the North American literature. *Environ. Rev.* 3:230–261.
- DODD, C.K. JR., AND R.M. DORAZIO. 2004. Using counts to simultaneously estimate abundance and detection probabilities in a salamander community. *Herpetologica* 60:468–478.
- DUPUIS, L.A., J.N.M. SMITH, AND F. BUNNELL. 1995. Relation of terrestrial-breeding amphibian abundance to tree-stand age. *Conserv. Biol.* 9:645–653.
- FRANKLIN, J.E., AND C.T. DYRNESS. 1988. *Natural vegetation of Oregon and Washington*. Oregon State University Press, Corvallis, OR. 452 p.
- GOMEZ, D.M., AND R.G. ANTHONY. 1996. Amphibian and reptile abundance in riparian and upslope areas of five forest types in western Oregon. *Northwest Sci.* 70:109–119.
- GOMI, T., R.C. SIDLE, AND J.S. RICHARDSON. 2002. Understanding processes and downstream linkages of headwater streams. *Bio-science* 52:905–916.
- GRIALOU, J.A., S.D. WEST, AND R.N. WILKINS. 2000. The effects of forest clearcut harvesting and thinning on terrestrial salamanders. *J. Wildl. Manag.* 64:105–113.
- GROVER, M.C. 1998. Influence of cover and moisture on abundances of the terrestrial salamanders *Plethodon cinereus* and *Plethodon glutinosus*. *J. Herpetol.* 32:489–497.
- HAGAR, J., S. HOWLIN, AND L. GANIO. 2004. Short-term response of songbirds to experimental thinning of young Douglas-fir forests in the Oregon Cascades. *For. Ecol. Manag.* 199:333–347.
- HARPOLE, D.N., AND C.A. HAAS. 1999. Effects of seven silvicultural treatments on terrestrial salamanders. *For. Ecol. Manag.* 114:349–356.
- HAYES, J.P., S.S. CHAN, W.H. EMMINGHAM, J.C. TAPPEINER, L.D. KELLOGG, AND J.D. BAILEY. 1997. Wildlife responses to thinning young forests in the Pacific Northwest. *J. For.* 95:28–33.
- HAYES, J.P., J.M. WEIKEL, AND M.M.P. HUSO. 2003. Response of birds to thinning young Douglas-fir forests. *Ecol. Applic.* 13:1222–1232.
- HYDE, E.J., AND T.R. SIMONS. 2001. Sampling Plethodontid salamanders: Sources of variability. *J. Wildl. Manag.* 65:624–632.
- JONES, L.L.C., W.P. LEONARD, AND D.H. OLSON. 2005. *Amphibians of the Pacific Northwest*. Audubon Society, Seattle, WA. 227 p.
- KARRAKER, N.E., AND H.H. WELSH JR. 2006. Long-term impacts of even-aged timber management on abundance and body condition of terrestrial amphibians in Northwestern California. *Biol. Conserv.* 131:132–140.
- KNAPP, S.M., C.A. HAAS, D.N. HARPOLE, AND R.L. KIRKPATRICK. 2003. Initial effects of clearcutting and alternative silvicultural practices on terrestrial salamander abundance. *Conserv. Biol.*

- MACCRACKEN, J.G. 2005. Effects of uneven-aged timber harvest on forest floor vertebrates in the Cascade Mountains of southern Washington. *For. Ecol. Manag.* 208:123–135.
- MARSH, D.M., AND N.G. BECKMAN. 2004. Effects of forest roads on the abundance and activity of terrestrial salamanders. *Ecol. Applic.* 14:1882–1891.
- MAXCY, K.A., AND J. RICHARDSON. 2000. Abundance and movements of terrestrial salamanders in second-growth forests of southwestern British Columbia. P. 295–301 in *Proceedings of a conference on the biology and management of species and habitats at risk*, vol. 1, Darling, L.M. (ed.). B.C. Ministry of Environment, Lands, and Parks, Victoria, B.C.
- MCCOMB, W.C., K. MCGARIGAL, AND R.G. ANTHONY. 1993. Small mammal and amphibian abundance in streamside and upslope habitats of mature Douglas-fir stands, western Oregon. *Northwest Sci.* 67:7–15.
- MORNEAULT, A.E., B.J. NAYLOR, L.S. SCHAEFFER, AND D.C. OTHMER. 2004. The effect of shelterwood harvesting and site preparation on eastern red-backed salamanders in white pine stands. *For. Ecol. Manag.* 199:1–10.
- NAUGHTON, G.P., C.B. HENDERSON, K.P. FORESMAN, AND R.L. MCGRAW II. 2000. Long-toed salamanders in harvested and intact Douglas-fir forests of western Montana. *Ecol. Applic.* 10:1681–1689.
- OLSON, D.H., S.S. CHAN, AND C.R. THOMPSON. 2002. Riparian buffers and thinning designs in western Oregon headwaters accomplish multiple resource objectives. P. 81–91 in *Congruent management of multiple resources: Proceedings from the Wood Compatibility Initiative Workshop*, Johnson, A.C., R.W. Haynes, and R.A. Monserud (eds.). USDA For. Serv. Gen. Tech. Rep. PNW-GTR-563.
- OLSON, D.H., R.S. NAUMAN, L.L. ELLENBURG, B.P. HANSEN, AND S.S. CHAN. 2006. *Ensatina eschscholtzii* nests at a managed forest site in Oregon. *Northwest. Natur.* 87:203–208.
- OLSON, D.H., AND C. RUGGER. 2007. Preliminary study of the effects of headwater riparian reserves with upslope thinning on stream habitats and amphibians in western Oregon. *For. Sci.* 53:331–342.
- OLSON, D.H., AND G. WEAVER. 2007. Vertebrate assemblages associated with headwater hydrology in western Oregon managed forests. *For. Sci.* 53:343–355.
- OVASKA, K. 1988. Spacing and movements of the salamander, *Plethodon vehiculum*. *Herpetologica* 44:377–386.
- OVASKA, K., AND P.T. GREGORY. 1989. Population structure, growth, and reproduction in a Vancouver Island population of the salamander *Plethodon vehiculum*. *Herpetologica* 45:133–143.
- PETRANKA, J.W. 1994. Response to impact of timber harvesting on salamanders. *Conserv. Biol.* 7:302–304.
- PETRANKA, J.W., M.E. ELDRIDGE, AND K.E. HALEY. 1993. Effects of timber harvesting on southern Appalachian salamanders. *Conserv. Biol.* 7:363–370.
- PETRANKA, J.W., AND C.K. SMITH. 2005. A functional analysis of streamside habitat use by southern Appalachian salamanders: Implications for riparian forest management. *For. Ecol. Manag.* 210:443–454.
- SCHOWALTER, T.D., Y.L. ZHANG, AND J.J. RYKKEN. 2003. Litter invertebrate responses to variable density thinning in western Washington forest. *Ecol. Applic.* 13:1204–1211.
- SHERIDAN, C.D., AND D.H. OLSON. 2003. Amphibian assemblages in zero-order basins in the Oregon Coast Range. *Can. J. For. Res.* 33:1452–1477.
- SMITH, C.K., AND J.W. PETRANKA. 2000. Monitoring terrestrial salamanders: Repeatability and validity of area-constrained cover object searches. *J. Herpetol.* 34:547–557.
- SOKAL, R.R., AND F.J. ROHLF. 1995. *Biometry*, 3rd ed. W.H. Freeman and Company, New York. 887 p.
- SUZUKI, N. 2000. *Effects of thinning on forest-floor vertebrates and analysis of habitat associations along ecological gradients in Oregon coastal Douglas-fir forests*. PhD dissertation, Oregon State University, Corvallis, OR. 168 p.
- SUZUKI, N., AND J.P. HAYES. 2003. Effects of thinning on small mammals in Oregon coastal forests. *J. Wildl. Manag.* 67:352–371.
- TOFT, C.A., AND P.J. SHEA. 1983. Detecting community-wide patterns: estimating power strengthens statistical inference. *Am. Nat.* 122:618–625.
- USDA AND USDI [US DEPARTMENT OF AGRICULTURE AND US DEPARTMENT OF INTERIOR]. 1994. *Record of decision for amendments for Forest Service and Bureau of Land Management planning documents within the range of the northern spotted owl (Northwest Forest Plan)*. US Department of Agriculture, Forest Service, and US Department of Interior, Bureau of Land Management, Portland, OR.
- VESELY, D.G., AND W.C. MCCOMB. 2002. Salamander abundance and amphibian species richness in riparian buffer strips in the Oregon Coast Range. *For. Sci.* 48:291–297.
- WELSH, H.H. JR., AND S. DROEGE. 2001. A case for using plethodontid salamanders for monitoring biodiversity and ecosystem integrity of North American forests. *Conserv. Biol.* 15:558–569.
- WESSELL, S.J. 2005. *Biodiversity in western Oregon managed forests: Leave islands as habitat for species assemblages*. MSc thesis, Oregon State University, Corvallis, OR. 161 p.