

BEYOND THE EDGE: RIPARIAN HABITAT USE AND FOREST MANAGEMENT  
EFFECTS ON STREAM SALAMANDERS IN THE SOUTHERN APPALACHIAN  
MOUNTAINS

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In Partial Fulfillment  
of the Requirements for the Degree

Doctor of Philosophy

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by  
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AUGUST 2007

The undersigned, appointed by the Dean of the Graduate School, have examined the dissertation entitled

BEYOND THE EDGE: RIPARIAN HABITAT USE AND FOREST MANAGEMENT  
EFFECTS ON STREAM SALAMANDERS IN THE SOUTHERN APPALACHIAN  
MOUNTAINS

presented by John A. Crawford

a candidate for the degree of Doctor of Philosophy

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**ABSTRACT**

The current biodiversity crisis has received a great deal of attention over the past two decades. As of 2006, the World Conservation Union (IUCN) found that of 40,177 species assessed using IUCN Red List criteria, 16,199 are now listed as threatened with extinction. They found that one out of every eight bird species, one out of every four mammal species, and one out of every three species of amphibians was at risk of extinction. While a number of factors have been attributed to the decline of amphibians (e.g., chemical pollution, disease, global climate change, introduction of exotic species), habitat loss and degradation are generally accepted as the main cause of this decline. Amphibians are especially sensitive to loss and degradation of habitat due to their unique life history requirements (i.e. most amphibians require both aquatic and terrestrial resources to complete their life cycle).

While there are many types of habitat loss and degradation (e.g., agriculture, land development), many studies have focused on the impacts of logging on wildlife populations and on ecosystem processes. For amphibians, much of the work has focused on pond-breeding amphibians or amphibians that do not require water for reproduction.

Little information, however, exists on the effects of logging on amphibians that require streams for reproduction. In order to mitigate the impacts of habitat alteration on stream amphibians, it is necessary to have a clear understanding of the role abiotic and biotic factors play in determining habitat use and abundance. Additionally, we must determine the effects of forest management practices, such as timber harvesting, have on amphibian populations in order to develop alternative management strategies.

I have used direct (e.g., area-constrained daytime searches, visual encounter nighttime searches) and indirect (laboratory studies) methods to estimate the habitat use of stream salamanders. Specifically, I have determined the core terrestrial habitat use and the abiotic and biotic factors associated with microhabitat use and abundance, as well as determining how stream salamanders respond to predators in altered environments. Further, I have demonstrated the effects even-aged timber harvesting has on stream salamander populations and how current United States Forest Service regulations on riparian buffer widths function to protect these populations.

My data show that core terrestrial habitat use, microhabitat use, and overall stream salamander abundance are dependent on leaf litter depth and soil moisture. Furthermore, as leaf litter depth and soil moisture are reduced as a result of even-aged timber harvesting, the core terrestrial habitat use and abundance of salamanders decrease as a result of fewer microhabitats being available. The decrease in suitable microhabitats available is accompanied by a resulting increase in competition between stream salamander species. Lastly, I found that current USFS regulations for riparian buffer widths are vastly inadequate to protect stream salamander populations from activities such as timber harvesting.

# Chapter 1

## INTRODUCTION

John A. Crawford

The current biodiversity crisis has received a great deal of attention over the past two decades. As of 2006, the World Conservation Union (IUCN) found that of 40,177 species assessed using IUCN Red List criteria, 16,199 are now listed as threatened with extinction (IUCN 2006). They found that one out of every eight bird species, one out of every four mammal species, and one out of every three species of amphibians was at risk of extinction (IUCN 2006). This follows the findings of Stuart et al. (2004), who indicated that amphibians are far more threatened than either birds or mammals. While a number of factors have been attributed to the decline of amphibians (e.g., chemical pollution, disease, global climate change, introduction of exotic species), habitat loss and degradation are generally accepted as the main cause of this decline (Wake 1998; Carey et al. 1999; Semlitsch 2000; Cushman 2006). Amphibians are especially sensitive to loss and degradation of habitat due to their unique life history requirements (i.e. most amphibians require both aquatic and terrestrial resources to complete their life cycle).

Salamander communities make up an important ecological component of many forested ecosystems and often exceed the combined biomass of other terrestrial vertebrates in the eastern United States (Burton & Likens 1975; Hairston 1987). In the southern Appalachian Mountains, headwater streams and associated riparian habitats

contain high levels of salamander diversity and abundance (e.g., *Desmognathus*, *Eurycea*, *Gyrinophilus*, *Plethodon*, and *Pseudotriton*). These salamanders are members of the family Plethodontidae and lack lungs with which to breathe, but instead utilize dermal respiration to breathe across the surface of the skin (Petranka 1998). Many genera of plethodontid salamanders inhabit streams and have biphasic life cycles that include an aquatic larval stage that is followed by a terrestrial adult stage (Petranka 1998). While stream salamanders are dependent on aquatic habitats for reproduction and larval development, terrestrial habitats are used for foraging and potentially overwintering (Barbour et al. 1969; Ashton & Ashton 1978). Terrestrial woodland salamanders of the genus *Plethodon* differ from stream salamanders in that they oviposit in terrestrial habitats and have direct development without an aquatic larval stage (Petranka 1998).

Habitat loss and degradation can result from a number of processes (e.g., land development, agriculture). Within the past decade a number of studies have examined the impacts of timber harvesting on wildlife populations (e.g., Gram et al. 2003; Constantine et al. 2004; Goldstein et al. 2005) and on ecosystem processes (e.g., Ash 1995; Swank et al. 2001; Wilkerson et al. 2006) in the United States. In the eastern part of the United States, the effects of timber harvesting have focused on a specific family of salamanders (Plethodontidae). There has been considerable debate as to the long-term impacts and recovery of plethodontid salamander populations as a result of even-aged timber harvesting in the southern Appalachian Mountain region (Ash & Pollock 1999). Petranka et al. (1993) found that mean abundance of salamanders was approximately five times higher in mature forests (>50 yrs old) versus forests that were recently clearcut (<10 yrs old). They estimated that it would take 50-70 years for salamander populations

to return to pre-disturbance levels. In contrast, Ash (1997) found that abundance of salamanders on clearcut plots decreased to approximately 30-50% of forested plots in the first year after timber harvest and were almost zero after the second year. However, he found that salamanders returned to clearcut plots 4-6 years post-disturbance and estimated that it would take 20-24 years for salamander populations to return to pre-disturbance levels. Despite this considerable work in the eastern United States, the majority of this research has focused on woodland salamanders (e.g., Petranka et al. 1993; Ash 1997; Harper & Guynn Jr. 1999). Yet, most species of the Plethodontidae require streams for reproduction and larval development, but the effects of timber harvesting on these salamanders remains an area in need of investigation.

To combat habitat loss and degradation in stream ecosystems (in addition to providing wildlife corridors and protecting essential habitat required for completing the life cycles of riparian species), riparian buffer strips adjacent to streams have been used in managed forests for more than two decades (Vesely & McComb 2002). Buffer strips protect water quality from activities such as agriculture and silviculture, which cause siltation and increased water temperatures (Lowrance et al. 1984; Jones et al. 1999; Vesely & McComb 2002). However, riparian buffer strips are not only critical to the protection of aquatic resources; they can play a role in the conservation of biodiversity. A number of studies have documented the importance of terrestrial habitat adjacent to streams and wetlands for semiaquatic species, including amphibians (e.g., deMaynadier & Hunter 1995; Semlitsch 1998; Vesely & McComb 2002). Although terrestrial buffer distances have been established for the protection of aquatic resources, little information exists for the explicit protection of semiaquatic species that require terrestrial habitat

adjacent to streams. In the Pacific Northwest (U.S.A.), a few studies have addressed this need (Corn & Bury 1989; McComb et al. 1993; Gomez & Anthony 1996; Vesely & McComb 2002). Of these studies, Vesely and McComb (2002) report that buffer strips of 20 m contain approximately 80% of detectable torrent salamanders (*Rhyacotriton* spp.), Pacific giant salamanders (*Dicamptodon tenebrosus*), and Dunn's salamanders (*Plethodon dunni*) along the first- through third-order streams they surveyed. However, the data are still relatively limited for stream salamanders in other areas of the United States.

In order to mitigate the impacts of habitat alteration on stream amphibians, it is necessary to have a clear understanding of the role abiotic and biotic factors play in determining habitat use and abundance. Additionally, we must determine the effects of forest management practices, such as timber harvesting, have on amphibian populations in order to develop alternative management strategies. I have used direct (e.g., area-constrained daytime searches, visual encounter nighttime searches) and indirect (laboratory studies) methods to estimate the habitat use of stream salamanders. Specifically, I have determined the core terrestrial habitat use and the abiotic and biotic factors associated with microhabitat use and abundance, as well as determining how stream salamanders respond to predators in altered environments. Further, I have demonstrated the effects even-aged timber harvesting has on stream salamander populations and how current United States Forest Service regulations on riparian buffer widths function to protect these populations.

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## Chapter 2

### ESTIMATION OF CORE TERRESTRIAL HABITAT FOR STREAM-BREEDING SALAMANDERS AND DELINEATION OF RIPARIAN BUFFERS FOR PROTECTION OF BIODIVERSITY

John A. Crawford and Raymond D. Semlitsch

#### **Abstract**

Many species of wildlife depend on riparian habitats for various life-history functions (e.g., breeding, foraging, over-wintering). Although this unique habitat is critical for many species, delineations of riparian zones and buffers for various taxa are lacking. Typically when buffer zones are determined to mitigate edge effects, they are based on criteria that protect aquatic resources alone, and do not consider impacts to wildlife and other terrestrial resources. Using two different survey methods (area-constrained daytime searches and nighttime visual encounter searches), we estimated core terrestrial habitat and buffer widths for stream-breeding salamanders in southern Appalachian streams from May to August 2004. A core terrestrial habitat of 27.0 m encompassed 95% of the salamander assemblage (four species of stream plethodontids) with an additional 50 m to buffer edge effects yielding a total buffer of 77.0 m. When each species of the assemblage was analyzed separately, the maximum core terrestrial habitat needed for the Blue Ridge two-lined salamander (*Eurycea wilderae*), a dominant member and the farthest-ranging species from the stream, was 42.6 m. Thus, we recommend an overall

buffer width of 92.6 m in southern Appalachian streams. To protect stream amphibians and other wildlife taxa dependent on riparian areas, land managers and policymakers must consider conserving more than aquatic resources alone. Developing core terrestrial habitat estimates and buffer zone widths for wildlife populations is a critical first step in the conservation of many semi-aquatic organisms and protecting biodiversity.

### **Introduction**

Concern over amphibian declines has increased dramatically over the past decade (e.g., Pechmann & Wilbur 1994; Blaustein et al. 1994; Houlahan et al. 2000). Stuart et al. (2004) indicated that amphibians are far more threatened than either birds or mammals. Although many factors have been implicated in this decline (e.g., disease, introduction of exotic species, chemical pollution, global climate change), habitat loss and degradation are generally accepted as the major factor responsible for most declines (e.g., Lips 1998; Wake 1998; Carey et al. 1999; Semlitsch 2000). Furthermore, many amphibians require both aquatic and terrestrial habitats to complete their life cycle and therefore are especially susceptible to the loss and degradation of either habitat (Semlitsch 2000).

To combat habitat loss and degradation in stream ecosystems (in addition to providing wildlife corridors and protecting essential habitat required for completing the life cycles of riparian species), riparian buffer strips adjacent to streams have been used in managed forests for more than two decades (Vesely & McComb 2002). Buffer strips protect water quality from activities such as agriculture and silviculture, which cause siltation and increased water temperatures (Lowrance et al. 1984; Jones et al. 1999;

Vesely & McComb 2002). However, riparian buffer strips are not only critical to the protection of aquatic resources; they can play a role in the conservation of biodiversity. A number of studies have documented the importance of terrestrial habitat adjacent to streams and wetlands for semiaquatic species, including amphibians (e.g., deMaynadier & Hunter 1995; Semlitsch 1998; Vesely & McComb 2002).

Salamander communities make up an important ecological component of many forested ecosystems and often exceed the combined biomass of other terrestrial vertebrates (Burton & Likens 1975; Hairston 1987; Petranka & Murray 2001). Some of these salamanders (e.g., *Desmognathus*, *Eurycea*, *Gyrinophilus*, *Pseudotriton*) are associated with streams and creeks. The four focal species of this study differ markedly in larval periods (*Desmognathus monticola*, 10 months; *D. ocoee*, 9 months; *D. quadramaculatus*, up to 4 yrs; *Eurycea wilderae*, up to 2 yrs) but all depend on aquatic habitats for reproduction and larval development (Petranka 1998). However, terrestrial habitats are used for foraging and potentially for overwintering (e.g., Barbour et al. 1969; Ashton & Ashton 1978). The three species of *Desmognathus* in this study spatially segregate themselves in the terrestrial habitat, most likely due to competition and predation (Hairston 1949; Organ 1961). The largest of the three species, the black-bellied salamander (*D. quadramaculatus*), occurs closest to the stream. The next largest species, the seal salamander (*D. monticola*), is slightly more terrestrial, and the Ocoee salamander (*D. ocoee*) is the most terrestrial of the three *Desmognathus* species and occurs the farthest from the stream edge. The Blue Ridge two-lined salamander (*E. wilderae*) occurs the farthest from the stream edge in the salamander assemblage (Crawford personal observation).

Although terrestrial buffer distances have been established for the protection of aquatic resources, little information exists for the explicit protection of semiaquatic species that require terrestrial habitat adjacent to streams. In the Pacific Northwest (U.S.A.), a few studies have addressed this need (Corn & Bury 1989; McComb et al. 1993; Gomez & Anthony 1996; Vesely & McComb 2002). Of these studies, Vesely and McComb (2002) report that buffer strips of 20 m contain approximately 80% of detectable torrent salamanders (*Rhyacotriton* spp.), Pacific giant salamanders (*Dicamptodon tenebrosus*), and Dunn's salamanders (*Plethodon dunni*) along the first-through third-order streams they surveyed. However, the data are still relatively limited for stream salamanders in other areas of the United States.

Typically when buffer zones are defined, they are based on criteria that protect the aquatic resources alone and do not consider impacts to semiaquatic species and other terrestrial resources (Semlitsch & Bodie 1998; Semlitsch & Jensen 2001). For example, in Oregon (U.S.A.) the minimum buffer strip required to protect water resources is 6.1 m although, a minimum buffer of 20 m is needed to protect certain salamander species (Vesely & McComb 2002). We defined core terrestrial habitat as the spatial delineation of 95% of the population that encompasses terrestrial foraging, breeding, and overwintering habitats rather than buffers, following Semlitsch and Jensen (2001). Although not all available habitat contained within these core areas is suitable at any one time, critical habitat patches (e.g., logs, piles of leaf litter, rocks) are contained within them. Determining core terrestrial habitats for stream-breeding salamanders is the critical first step in formulating conservation plans and addressing larger-scale issues such as connectivity among populations.

We sought to develop biologically based management criteria to protect stream salamanders. Specifically, we defined the core terrestrial habitat used by an assemblage of four species of stream salamanders to provide recommendations on appropriate stream buffer widths. We also devised a direct test of whether day versus night sampling yields the best estimate of core terrestrial habitat for these salamanders.

## **Methods**

To define core terrestrial habitat use by an assemblage of stream salamanders, we sampled riparian forests adjacent to 14 headwater streams (streams were the unit of replication) in the southern Appalachian Mountains, Nantahala National Forest, Macon County, North Carolina (U.S.A.). All sites were located between 718 and 1248 m elevations, had not been subject to logging for at least 80 years, and were located at least 1 km apart (Table 1). To insure maximum capture success and detection of rare species (Hyde & Simons 2001), we used two different sampling methods. Sites were sampled six times each (three day transects, three night transects) from May-August of 2004.

During day transects, we monitored one paired transect that was separated by 1 m (to increase sample sizes of salamanders; data for each plot were combined) and extended perpendicular from the stream bank into the adjacent forest. Monitoring stations were established at 1, 3, 7, 10, 15, 25, 50, and 100 m from the stream bank, based on the home range sizes and potential distances traveled by the target species of stream-breeding salamanders. At each stream we checked daytime transects by conducting area-constrained searches ( $2.25 \text{ m}^2$ ) of leaf litter and coarse woody debris at each monitoring

station for an average of 10 minutes. We used a visual encounter search (VES) during the three night transects to capture surface-active salamanders. Two researchers walked a straight line that was perpendicular from the stream edge (defined as the edge of the streambed) out to 100 m and recorded distance from the stream edge for each salamander encountered. While walking the perpendicular transect, each researcher searched 2.5 m to the right and left of the transect line. We identified all salamanders (day and night transects) to species, weighed and measured for snout-vent length and total length, and determined sex. We released all salamanders at the site of capture. We determined age class (adult/juvenile) by comparing measured snout-vent lengths of each individual to published size classes for each species (Petranka 1998).

Average distance salamanders were found from the stream was calculated across the 14 streams and was tested for normality with Wilk's Lambda (data in Table 2). To find the distance from the stream edge that would encompass the majority of each species of salamander and the assemblage an upper confidence interval was calculated.

## **Results**

Four species of stream salamanders, the seal salamander, the Ocoee salamander, the black-bellied salamander, and the Blue Ridge two-lined salamander were encountered during 2004. These salamanders were found an average of 8.4 m from the edge of their aquatic habitats during day transects and 24.4 m during the night transects (Table 2). If we assumed the distances of salamanders from the edge of streams were normally distributed, then by definition the mean of salamanders of all species (8.4 m day, 24.4 m

night) represents a distance that includes only 50% of the assemblage. Although the distribution for the night transects had a normal distribution ( $W = 0.939$ ,  $p = 0.441$ ), the distribution for the day transects had a non-normal distribution ( $W = 0.820$ ,  $p = 0.01$ ). This non-normal distribution was due to the sampling of monitoring stations that were not equally distributed (1, 3, 7, 10, 15, 25, 50, and 100 m from the stream edge) and the fact that not all habitat could be sampled from stream edge out to 100 m. A distance of 27.0 m from the stream's edge encompassed 95% of the total salamander assemblage (adults and juveniles of all species) based on capture data from the night transects. The average distance adults were found from the stream was only slightly larger than the distance for juveniles (adults, 29.6 m; juveniles, 25.5 m) and marginally significant ( $p = 0.086$ ,  $df = 26$ ). The farthest-ranging species from streams in our assemblage (*E. wilderae*) yielded a 95% confidence interval of 42.6 m (Table 3).

To determine whether day or night sampling yielded the best estimate of salamander distribution from the stream, we made a direct comparison. Captures from the night transects were adjusted and a mean distance from the stream was calculated for direct testing with day transects. Only animals captured within 2.25 m<sup>2</sup> plots at each of the day sampling distances were used for the night adjusted values. Time spent searching these plots was approximately equal to daytime sampling (10 minutes) to equalize search intensity. Distribution estimates were significantly different between day and night transects ( $p = 0.033$ ,  $df = 26$ ). Day transects yielded a mean distance from the stream of 8.4 m (10.7 m encompassed 95% of the assemblage), whereas night transects had a mean distance from the stream of 12.6 m (15.8 m encompassed 95% of the assemblage).

The number of dusky (*Desmognathus*) salamanders decreased sharply with distance from the stream edge (Fig. 1). The number of brook (*Eurycea*) salamanders remained somewhat constant from the stream edge into the forest for 70 to 75 m (Fig. 1). The majority of dusky salamanders were found within 15 m of the stream's edge whereas brook salamanders were found at very low numbers near the stream edge and did not increase in number until 15-20 m from the stream's edge (Fig. 1). Overall the distribution of all salamanders from the edge of the streams showed a relatively smooth decline as distance from the stream increased.

## **Discussion**

Salamanders generally comprise the greatest biomass of any vertebrates in forested ecosystems (Burtons & Likens 1975; Petranka & Murray 2001) and thus are of vital importance to the ecosystem as a whole because they consume invertebrates and serve as prey for other vertebrates. Many stream-dwelling salamanders are highly philopatric and long-lived, and typically exist in relatively stable populations (Welsh Jr. & Ollivier 1998). These traits make them reliable indicators of potential biotic diversity in stream and riparian ecosystems, and their relative abundance can be a critical indicator of stream and riparian ecosystem health (Welsh Jr. & Ollivier 1998). Determining and maintaining the terrestrial habitat that salamanders require is critical to maintaining existing populations and potentially ecosystem function. With accurate estimates of core terrestrial habitat, policy makers and land managers will be better equipped to make

management decisions pertaining to stream salamanders and potentially other species that rely on riparian habitats (e.g., reptiles, birds, mammals).

During the past 10-15 years, increased attention has focused on defining and delineating riparian areas. In Texas Rudolph and Dickson (1990) captured more amphibians in wide buffers (50-95 m) versus narrow buffers (0-25 m) along intermittent streams that passed through even-aged pine plantations. They recommend 30-m buffers for amphibians. deMaynadier and Hunter (1995) recommend buffers of 10 to 25 m along streams surrounded by a wider management zone where partial harvesting of trees could occur. Vesely and McComb (2002) found that 47 m buffers along first-, second-, and third-order streams were necessary to support amphibian assemblages similar to those in unlogged forests in Oregon. Although many of these studies provide buffer recommendations, they actually provide core terrestrial habitat estimates and do not include a true buffer from the edge effects caused by surrounding land use.

We used two sampling methods (day transects versus night transects) to determine the most appropriate way to yield core terrestrial habitat estimates for stream-breeding salamanders. We defined core terrestrial habitat as the spatial delineation of 95% of the population that encompasses terrestrial foraging, breeding, and overwintering habitats, which was determined by the 95% confidence interval. The day transects yielded a core terrestrial habitat estimate of 10.7 m, whereas the adjusted night transects yielded a significantly different core terrestrial habitat estimate of 15.8 m. This comparison and distinction is important because most plethodontid monitoring techniques employ only daytime searches. In our study, the daytime searches lead to inadequate estimation of the amount of habitat salamanders require. The overall night

transects yielded a core habitat estimate of 27.0 m that was more than double the estimate based on day transects.

Because of the importance of core terrestrial habitat to population persistence, a buffer is necessary to reduce potential edge effects that can penetrate great distances into forested habitats (Murcia 1995; deMaynadier & Hunter 1995). Therefore, to fully protect the salamander assemblage, we recommend applying a stream buffer of 50 m. Although edge effects can extend farther than 50 m (e.g., Murcia 1995; Haskell 2000), the amount of edge needed to protect core terrestrial habitat for salamanders is poorly resolved for southern Appalachian forests, so we view 50 m as conservative. This recommendation is supported by Marsh and Beckman (2004), who found edge effects for red-backed salamanders (*Plethodon cinereus*) that range from 20 m to 80 m (80 m in a dry year). Similarly, 20-m edge effects were found for red-backed salamanders in New Hampshire (deGraaf & Yamasaki 2002). Thus, 50 m should adequately protect the core terrestrial habitat of this salamander assemblage, especially under all but dry conditions or on more exposed south-facing slopes.

The two different genera we encountered have drastically different core terrestrial habitat requirements. Although the difference in core terrestrial habitat usage between adults and juveniles within each genus was minimal, the difference between dusky salamanders and brook salamanders was large (8.5 m for dusky vs. 42.6 m for brook). Current U.S. Forest Service (USFS) guidelines for southern Appalachian streams require an ~ 9-m (30 feet) buffer for headwater through second-order streams and an ~ 30-m (100 feet) buffer for streams third-order and above. The USFS buffer regulations would not be

adequate to protect brook salamanders in smaller streams and would provide dusky salamanders with little protection from edge effects.

Both of these genera are in the family Plethodontidae, which is a lungless family of salamanders (Petranka 1998). This means these salamanders are even more dependent on moist habitats for respiration than other families of amphibians. In instances where there is only a 9-m buffer along the stream, brook salamanders would be forced into an “ecological decision” between two adverse environments. The majority of dusky salamanders resided within 15 m of the stream’s edge, whereas brook salamanders occurred primarily 15-20 m from the stream’s edge (Fig. 1). This is most likely due to predation and competition pressures exerted by the larger dusky salamanders on the brook salamanders. Both black-bellied salamanders and seal salamanders prey on juvenile and adult two-lined salamanders (Beachy 1993; Crawford personal observation). Thus, the brook salamanders might choose to remain in less suitable habitat (e.g., drier, no leaf litter), risking desiccation and potential death, or they might choose to move closer to the stream and face higher risks of predation and greater rates of competition from dusky salamanders. Both these scenarios would likely lead to increased mortality and a decline in population numbers (e.g., Hairston 1987; Jaeger et al. 1998). It also assumes that all 9 m of the buffer will be equally suitable habitat, which is unrealistic because edge effects would extend completely through this small area.

We would argue that our core terrestrial habitat estimate of 27.0 m for a stream salamander assemblage is conservative. Although this value is similar to the core habitat estimates of Petranka and Smith (2005), their estimates for some species were limited. They are limited because their terrestrial survey plots extended only 36-38 m from the

stream, so animals occurring farther from the stream were not sampled. Our core terrestrial habitat value was calculated with all four stream species found in the assemblage; however the estimate failed to fully protect one of the dominant species (*E. wilderae*). If the overall goal of core terrestrial habitats and buffer zones is to protect both diversity and abundance of an assemblage, we suggest calculating individual estimates for each species and using the greatest core terrestrial habitat estimate. This ensures protection of each species within the assemblage. Based on our results for *E. wilderae* alone, we recommend a core terrestrial habitat of 42.6 m and an overall buffer width of 92.6 m in southern Appalachian streams.

Although research on riparian habitats is increasing, a great deal of information is still lacking for many taxa requiring these habitats. We found that there are approximately 173 terrestrial vertebrates in the eastern United States alone that require riparian habitats for some life-history function (26 mammals, 27 birds, 50 reptiles, and 70 amphibians; unpublished data). More information on core terrestrial habitats and buffer zone widths is needed to strike a balance between conservation and sustainable land use. However, we have provided a reliable estimate of core terrestrial habitat required by southern Appalachian stream salamanders and an appropriate survey methodology that can be used in other regions to estimate core habitats. We hope that this research will provide land managers and policymakers with more information on which to delineate riparian buffer zones and will stimulate future work in these critical habitats.

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**Table 1.** Habitat characteristics of stream sites used in the Nantahala National Forest, North Carolina.

<i>Locality (UTM)</i>	<i>Stream Order</i>	<i>Canopy (%)</i>	<i>Slope</i>	<i>Forest Type</i>
17S 0301518 3881167	Headwater	91.2%	15.5°	Pine
17S 0304637 3879204	Headwater	87.6%	15.5°	Mixed deciduous
17S 0304364 3879082	Headwater	90.3%	13.5°	Mixed deciduous
17S 0302750 3876075	Headwater	88.5%	17.5°	Pine
17S 0301733 3876558	Headwater	90.2%	21.7°	Mixed deciduous
17S 0298076 3878383	Headwater	90.2%	12.1°	Mixed deciduous
17S 0297721 3878097	Headwater	91.6%	24.2°	Mixed deciduous
17S 0296901 3878721	Headwater	90.4%	17.5°	Mixed deciduous
17S 0295741 3876678	Headwater	88.0%	30.0°	Mixed deciduous
17S 0295829 3876035	Headwater	89.2%	13.5°	Pine
17S 0297122 3885702	Headwater	93.2%	19.3°	Mixed deciduous
17S 0296072 3886657	Headwater	88.4%	14.6°	Pine
17S 0297839 3885471	Headwater	90.3%	19.3°	Mixed deciduous

17S 0301596 3879760	Headwater	91.8%	14.5°	Mixed deciduous
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**Table 2.** Summary of occurrence distances<sup>a</sup> (m) from stream edge of a stream salamander assemblage in the southern Appalachian Mountains.

<i>Species (transect type)<sup>b</sup></i>	<i>Adults</i>	<i>Juveniles</i>	<i>All age classes</i>
Stream day	10.0, 13.4 n = 107	6.3, 8.7 n = 95	8.4, 10.7 n = 202
Stream night	26.0, 29.6 n = 280	21.5, 25.5 n = 211	24.4, 27.0 n = 491
<i>Desmognathus</i> day	5.2, 7.5 n = 74	3.8, 5.8 n = 79	5.1, 7.4 n = 153
<i>Desmognathus</i> night	7.5, 9.2 n = 130	6.6, 8.0 n = 104	7.3, 8.5 n = 234
<i>Eurycea</i> day	17.9, 24.1 n = 33	18.5, 24.5 n = 16	18.4, 23.4 n = 49
<i>Eurycea</i> night	41.0, 44.1 n = 150	36.4, 43.2 n = 107	39.3, 42.6 n = 257

<sup>a</sup>Distance encompassing 50% and 95% of the population, respectively.

<sup>b</sup>Stream denotes salamanders in the assemblage (*Desmognathus monticola*,

*D. quadramaculatus*, *D. ocoee*, and *Eurycea wilderae*). *Desmognathus* denotes 3 species

in the genus (*D. monticola*, *D. quadramaculatus*, and *D. ocoee*). *Eurycea* denotes 1

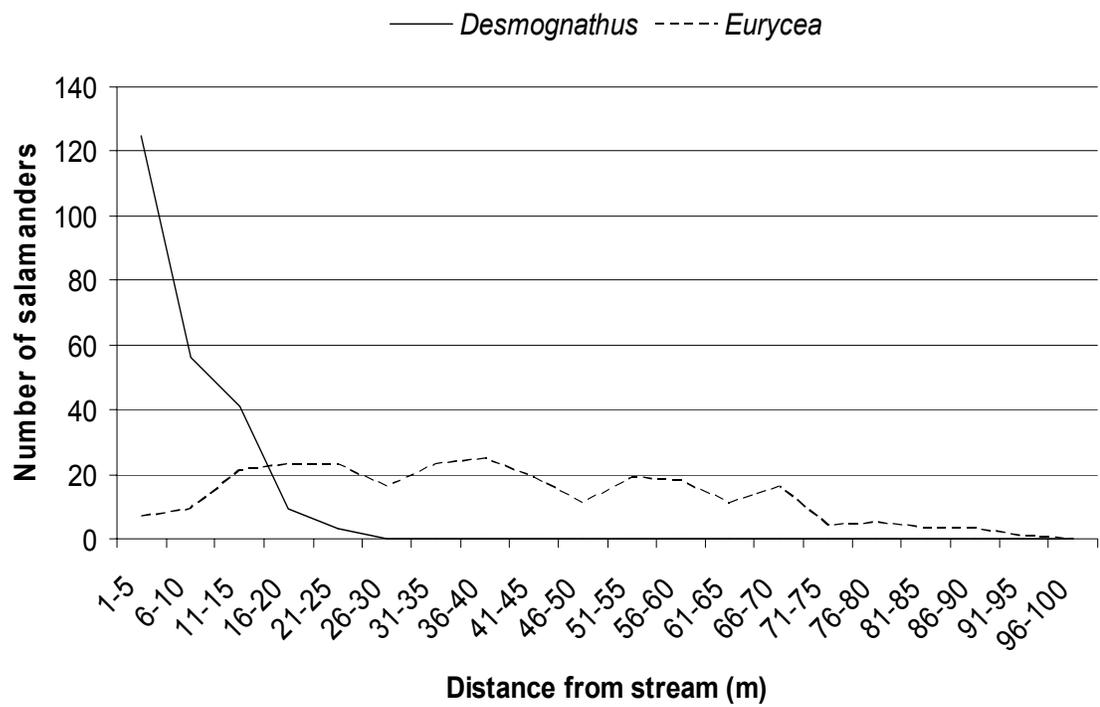
species in the genus (*Eurycea wilderae*).

**Table 3.** Summary of occurrence distances<sup>a</sup> (m) from stream edge for individual stream salamander species in the southern Appalachian Mountains.

<i>Species (transect type)</i>	<i>Adults</i>	<i>Juveniles</i>	<i>All age classes</i>
<i>D. monticola</i> day	4.6, 6.7 n = 22	3.1, 5.6 n = 20	3.8, 5.4 n = 42
<i>D. monticola</i> night	6.8, 8.6 n = 64	5.1, 7.7 n = 30	6.6, 8.8 n = 94
<i>D. ocoee</i> day	5.6, 8.6 n = 48	4.4, 7.2 n = 59	5.5, 8.3 n = 107
<i>D. ocoee</i> night	10.4, 13.8 n = 43	7.3, 9.5 n = 74	8.2, 9.7 n = 117
<i>D. quadramaculatus</i> day	2.0, 4.5 n = 4	N/A n = 0	2.0, 4.5 n = 4
<i>D. quadramaculatus</i> night	3.2, 4.7 n = 23	N/A n = 0	3.2, 4.7 n = 23
<i>E. wilderae</i> day	17.9, 24.1 n = 33	18.5, 24.5 n = 16	18.4, 23.4 n = 49
<i>E. wilderae</i> night	41.0, 44.1 n = 150	36.4, 43.2 n = 107	39.3, 42.6 n = 257

<sup>a</sup>Distance encompassing 50% and 95% of the population, respectively.

**Figure 1.** Distribution of dusky (*Desmognathus*) and brook (*Eurycea*) salamanders from edges of headwater streams in the Nantahala National Forest, North Carolina (based on nighttime visual encounter searches).



## Chapter 3

### ABIOTIC FACTORS INFLUENCING ABUNDANCE AND MICROHABITAT USE OF STREAM SALAMANDERS IN THE SOUTHERN APPALACHIAN MOUNTAINS

John A. Crawford and Raymond D. Semlitsch

#### **Abstract**

In order to evaluate the effects of habitat loss and degradation on amphibian populations it is necessary to determine of species-specific habitat use and how this influences abundance. While a number of studies have examined the influence of competition and predation in stream salamander assemblages of the southern Appalachian Mountains, there remains a relative lack of knowledge on the microhabitat use of these species. Using area-constrained daytime searches, we investigated microhabitat use and abundance for stream-breeding salamanders in mature forests in southern Appalachian streams from May to August 2004. We found that leaf litter depth, soil moisture, and canopy cover were all higher and soil temperature was lower in plots where stream salamanders were found compared to plots where salamanders were not encountered. A regression analysis using the information theoretic approach (AIC) revealed that the model that included distance from stream, leaf litter depth, soil moisture, and soil temperature had the strongest support for predicting stream salamander abundance at the landscape level ( $\omega_1 = 0.99$ ). Microhabitat use in many species of stream salamanders is mediated by a number of complex factors including environmental variables,

competition, and predation. Alteration of habitats likely results in increased competition and predation rates and subsequent population declines, so it is imperative to mitigate the effects of practices such as even-aged timber harvesting in order to conserve amphibian biodiversity.

## **Introduction**

The effects of habitat loss and degradation on amphibians are often pronounced because of their relatively low vagilities and narrow habitat tolerances (Gibbs 1998; deMaynadier & Hunter 2000; Semlitsch 2000; Houlahan & Findlay 2003). Many studies have shown a positive relationship between amount of forest cover and amphibian species occurrence and richness (Gibbs 1998; Guerry & Hunter 2002; Trenham & Shaffer 2005). Despite this generalization, determination of species-specific habitat use is necessary in order to understand the effects of habitat loss and degradation on amphibian populations (Cushman 2006), and mitigate effects through conservation plans.

Salamander communities make up an important ecological component of many forested ecosystems and often exceed the combined biomass of other terrestrial vertebrates in the eastern United States (Burton & Likens 1975; Hairston 1987). In the southern Appalachian Mountains, headwater streams and associated riparian habitats contain high levels of salamander diversity and abundance (e.g., *Desmognathus*, *Eurycea*, *Gyrinophilus*, *Plethodon*, and *Pseudotriton*). These salamanders are members of the family Plethodontidae and lack lungs with which to breathe, but instead utilize dermal respiration to breathe across the surface of the skin (Petranka 1998). Many genera of

plethodontid salamanders inhabit streams and have biphasic life cycles that include an aquatic larval stage that is followed by a terrestrial adult stage (Petranka 1998). While stream salamanders are dependent on aquatic habitats for reproduction and larval development, terrestrial habitats are used for foraging and potentially overwintering (Barbour et al. 1969; Ashton & Ashton 1978). Terrestrial woodland salamanders of the genus *Plethodon* differ from stream salamanders in that they oviposit in terrestrial habitats and have direct development without an aquatic larval stage (Petranka 1998).

Although plethodontid salamanders have been the focus of demographic and behavioral studies in the southern Appalachian Mountains for more than five decades (e.g., Hairston 1949; Organ 1961, Hairston 1987), information on habitat use is still lacking. More recently a few studies have begun to address how salamanders are distributed across the landscape and the environmental factors that affect their distribution (e.g., Grover 2000; Moore et al. 2001; Petranka and Smith 2005; Crawford and Semlitsch 2007). In stream salamander assemblages in western North Carolina, Crawford and Semlitsch (2007) found four focal species that were spatially separated from one another. The majority of dusky salamanders (*Desmognathus quadramaculatus*, *D. monticola*, and *D. ocoee*) resided within 15 m of the stream's edge, whereas brook salamanders (*Eurycea wilderae*) occurred primarily beyond 15-20 m (and up to 100 m) from the stream's edge. This is most likely due to predation and competition pressures exerted by the larger dusky salamanders on the brook salamanders (Southerland 1986a; Hairston 1987). Both black-bellied salamanders (*D. quadramaculatus*) and seal salamanders (*D. monticola*) are large bodied and prey on juvenile and adult two-lined salamanders (Beachy 1993; Crawford personal observation). Grover (2000) found that

among both terrestrial and stream salamanders, larger species used wider cover objects, deeper retreats, and occupied cooler retreat sites than smaller species. Among the stream salamanders, larger species were found closer to water than smaller species and the rehydration rates of the smaller species that were found further from the stream were higher than those of larger species found closer to the stream (Grover 2000). The unique physiology of plethodontid salamanders makes them very susceptible to dehydration and restricts their activity to periods when humidity and soil moisture are high (Spotila 1972; Tracy 1976). While a number of studies have documented the importance of soil moisture to stream salamanders, understanding what habitat features are associated with soil moisture and salamander abundance is essential.

We sampled stream salamanders in the riparian areas along headwater streams to determine what environmental variables were most important for microhabitat use and their relationship to distance from the stream edge. We used regression analyses with an information-theoretic approach to select which environmental variables would best predict relative abundance of stream salamanders in riparian habitats.

## **Methods**

### Study Area

To determine habitat use and stream salamander abundance, we sampled riparian forests adjacent to 14 headwater streams in the southern Appalachian Mountains, Nantahala National Forest, Macon County, North Carolina (U.S.A.). All sites were located between 718-1248 m in elevation, had not been subject to logging for at least 80 years and were

located at least 1 km apart. Sites were sampled three times each from May to August of 2004 using an area-constrained daytime search.

### Sampling Protocol

During sampling, we collected stream salamanders at paired transects that were separated by at least 1 m and extended perpendicular from the stream bank into the adjacent forest. Monitoring stations were established at 1, 3, 7, 10, 15, 25, 50, and 100 m from the stream bank, based on the home range sizes and potential distances traveled by the target species of stream-breeding salamanders (Crawford & Semlitsch 2007). At each stream, we conducted the three collections by using area-constrained searches of each plot (2.25 m<sup>2</sup>) by sifting through leaf litter and coarse woody debris at each monitoring station for an average of 10 minutes. At each plot, data was collected on four environmental variables: 1) Leaf litter depth – measured three times in each plot (6 times per station) using a hand ruler for an average leaf litter depth value; 2) Soil temperature – measured three times in each plot (6 times per station) using an infrared Raytek® MT4 temperature gun for an average temperature value; 3) Soil moisture – measured three times in each plot (6 times per station) using an Aquaterr® M300 soil moisture meter for an average soil moisture value; and 4) Canopy cover – measured one time in each plot (2 times per station) using a spherical crown densiometer for an average canopy cover value. Additionally, slope and altitude were recorded for each of the 14 sites.

We identified all salamanders to species, weighed and measured for snout-vent length and total length, determined sex, and recorded the distance from the stream. We released all salamanders at the site of capture. We determined age class (adult or

juvenile) by comparing measured snout-vent lengths of each individual to published size classes for each species (Petranka 1998).

### Data Analysis

To investigate the relationships between stream salamander abundance and environmental variables, we used an information-theoretic approach to model selection (Burnham and Anderson 2002). The information-theoretic approach allows one to select a “best” model and to rank the remaining models (Burnham and Anderson 2002).

Burnham and Anderson (2002) suggest the information-theoretic approach should be used in observational studies where other hypothesis testing methods may lead to “data dredging” and over-fitted models. Using 9 environmental variables, we built 16 *a priori* models to test hypotheses predicting stream salamander abundance. The environmental variables we selected (and subsequent models we built) were based on previous studies detailing their importance to plethodontid salamanders as well as pilot data collected during the 2003 field season. The predictive models are: (1) Null (intercept only); (2) Site (site); (3) Period (sampling period); (4) Distance (distance from stream); (5) Leaf (leaf litter depth); (6) Temperature (surface soil temperature); (7) Moisture (soil moisture); (8) Canopy (canopy cover); (9) Slope (terrestrial slope); (10) Elevation (altitude of site); (11) Soil (soil moisture and soil temperature); (12) Forage (soil moisture and leaf litter depth); (13) Gradient (soil moisture and distance from stream); (14) Microhabitat (soil moisture, soil temperature, and leaf litter depth); (15) Macrohabitat (canopy cover, slope, and elevation); and (16) Global (site, period, distance from stream, leaf litter depth, soil temperature, soil moisture, canopy cover, slope, and elevation).

For each model, we calculated the AIC value corrected for small sample sizes ( $AIC_c$ ), which is a measure of model fit adjusted for the number of parameters (Burnham and Anderson 2002).  $AIC_c$  values were derived from loglinear regressions with a poisson distribution using the generalized linear model in SPSS (v. 15). We ranked all candidate models according to their  $AIC_c$  values, and the best model had the smallest  $AIC_c$  value (Burnham and Anderson 2002). We also calculated  $\Delta AIC_c$ , which is the difference in AIC between each model and the best model in the set. AIC differences less than two are considered to indicate little difference between models, while differences of 4-7 indicate considerably less support for the model with the higher AIC value although it may have some empirical support (Burnham and Anderson 2002). Last, we calculated Akaike weights ( $\omega_i$ ) to determine the weight of evidence in favor of each model and to estimate the relative importance of each individual parameter (Burnham and Anderson 2002). Based on these results we also generated 6 post-hoc models using subsets of the variables included in each of the 16 *a priori* models. The post-hoc predictive models are: (1) DistLeaf (distance from stream and leaf litter depth); (2) DistLeafMois (distance from stream, leaf litter depth, and soil moisture); (3) DistLeafMoisTemp (distance from stream, leaf litter depth, soil moisture, and soil temperature); (4) DistLeafTemp (distance from stream, leaf litter depth, and soil temperature); (5) DistTemp (distance from stream and soil temperature); and (6) TempLeaf (soil temperature and leaf litter depth).

## Results

In 2004, stream salamanders were found in 149 of the 672 plots (N = 16 plots x 14 sites x 3 collections) that were searched (Figure 1). A total of 204 stream salamanders were captured in the 149 plots, including 107 Ocoee salamanders (*Desmognathus ocoee*), 42 seal salamanders (*D. monticola*), 4 black-bellied salamanders (*D. quadramaculatus*), 49 Blue Ridge two-lined salamanders (*Eurycea wilderae*), and 2 three-lined salamanders (*E. guttolineata*). Average leaf litter depth, average soil moisture, and average canopy cover were all lower and average soil temperature was higher in plots without a stream salamander of any species compared to plots where each stream salamander was captured (Table 1). For seal salamanders the average leaf litter depth, average soil moisture, and average canopy cover were all lower and average soil temperature was higher in plots without a seal salamander compared to plots where each seal salamander was captured (Table 2); for Ocoee salamanders the average leaf litter depth, average soil moisture, and average canopy cover were all lower and average soil temperature was higher in plots without an Ocoee salamander compared to plots where each Ocoee salamander was captured (Table 3); for two-lined salamanders the average leaf litter depth, average soil moisture, average canopy cover, and average soil temperature were all lower in plots without a two-lined salamander compared to plots where each two-lined salamander was captured (Table 4). We excluded plot data for black-bellied salamanders and three-lined salamanders due to low capture numbers.

Of the 16 *a priori* models, the Global model best predicted the abundance of stream salamanders (Table 5). This model included all 9 variables, however, distance from stream, leaf litter depth, soil moisture, and soil temperature were the only variables

for which the estimate of beta had a confidence interval that did not overlap zero (Table 6). One of the 6 post-hoc models described the data as well or better than the *a priori* global model (Table 7). A model including only the variables: distance from stream, leaf litter depth, soil moisture, and soil temperature ranked highest. The best *a priori* models for predicting seal salamander abundance were the Gradient model that included both distance from the stream and soil moisture and the Distance model that included only distance from the stream (Table 8). The only variables for which the estimate of beta had a confidence interval that did not overlap zero were distance from the stream and leaf litter depth (although soil moisture was also close; Table 9). Four of the 6 post-hoc models described the data as well or better than the *a priori* Gradient model (Table 10). A model including only the variables: distance from the stream and leaf litter depth ranked highest. The best *a priori* model for predicting Ocoee salamander abundance was the Global model (Table 11) This model included all 9 variables, however, distance from stream, leaf litter depth, soil moisture, and soil temperature were the only variables for which the estimate of beta had a confidence interval that did not overlap zero (Table 12). One of the 6 post-hoc models described the data as well or better than the *a priori* Global model (Table 13). A model including only the variables: distance from stream, leaf litter depth, soil moisture, and soil temperature ranked highest. The best *a priori* models for predicting two-lined salamander abundance were the Forage model that included leaf litter depth and soil moisture and the Microhabitat model that included leaf litter depth, soil moisture, and soil temperature (Table 14). The only variables for which the estimate of beta had a confidence interval that did not overlap zero were leaf litter depth and the intercept (Table 15). None of the 6 post-hoc models described the data as well or better

than the *a priori* Forage model (Table 16). Species-specific models were not tested for black-bellied salamanders and three-lined salamanders due to low capture numbers.

## **Discussion**

Many stream-breeding salamanders are highly philopatric, long-lived, and usually exist in relatively stable populations (Hairston 1987). These life history traits make them reliable indicators of potential biotic diversity in stream and riparian ecosystems, and their relative abundance and core habitat use can be a critical indicator of stream and riparian ecosystem health (Welsh Jr. & Ollivier 1998; Crawford & Semlitsch 2007). In eastern United States forests, salamanders typically comprise the greatest biomass of any vertebrates (Burton & Likens 1975; Petranka & Murray 2001) and serve a key role in the ecosystem because they consume invertebrates and serve as prey for other vertebrates. While numerous studies have documented the importance of competition and predation in structuring stream salamander assemblages and their distributions (e.g., Southerland 1986b; Hairston 1987; Roudebush & Taylor 1987), relatively fewer studies have examined the importance of environmental factors in undisturbed habitats. Of these studies, Keen (1984) found that dusky salamanders (*Desmognathus fuscus*) were found under smaller rocks more frequently on high moisture than low moisture substrates. However, during times of low moisture, salamanders used larger rocks more frequently and were more clumped in their dispersion pattern than on high moisture substrates (Keen 1984).

We found that leaf litter depth, soil moisture, and canopy cover were all higher and soil temperature was lower in plots where stream salamanders were found. Additionally our regression analyses revealed that the model that included distance from the stream, leaf litter depth, soil moisture, and soil temperature had the strongest support for predicting stream salamander abundance. These were also the four variables whose beta estimates did not overlap zero (Table 6). For each of the three individual species (seal salamanders, Ocoee salamanders, and two-lined salamanders) both leaf litter depth and soil moisture were higher in plots where these species were found. Leaf litter depth and soil moisture were also the only two variables that were consistently important in the highest ranked species-specific models from the regression analyses. Salamanders in the family Plethodontidae, which is a lungless family of salamanders (Petranka 1998), are even more dependent on moist habitats for dermal respiration than other families of amphibians. These salamanders forage for invertebrates in the leaf litter and when this leaf litter becomes thinner, the soil becomes drier, or both it is unlikely they will have the moisture necessary to carry on dermal respiration. Jaeger (1980) found that the percentage of red-backed salamanders (*Plethodon cinereus*) under rocks and logs increased and the percentage of salamanders in the leaf litter decreased with decreasing rainfall. Additionally, individuals cannot forage during dry periods because of the high rates of water loss (Jaeger 1972; Spotila 1972).

Selection of microhabitats is further mediated by both competition from conspecifics and heterospecifics as well as predator-prey interactions (Jaeger 1972; Southerland 1986a; Colley et al. 1989). Jaeger (1972) found that during periods of drought that prey items for salamanders decreased due to decreases in soil moisture and

leaf litter moisture. Eastern red-backed salamanders (*Plethodon cinereus*), which were presumably superior competitors, inhabited isolated pockets where soil moisture was higher and forced the Shenandoah salamanders (*P. shenandoah*) to reside in the much drier talus slopes. In the southern Appalachians, Southerland (1986b) found that the larger black-bellied salamanders (*D. quadramaculatus*) sharply reduced survival of juvenile seal salamanders (*D. monticola*) and caused shifts in activity and habitat selection. In the 149 plots that we found stream salamanders, only 11 of these plots had salamanders of two or more species (Figure 1). This also suggests that competition and predation may be important in microhabitat use.

In the southern Appalachian Mountains, clear-cutting of forests results in reduced litter dry mass (amount of leaf litter), leaf litter depth, and leaf litter moisture (Ash 1995). Additionally, Covington (1981) found that “forest floor organic matter” declined 55% over the first 15 years after logging. Logging activities have been shown to cause dramatic salamander declines in a number of studies and return of salamander populations to pre-disturbance levels can take up to 70 years (e.g., Petranka et al. 1993, Ash 1997; Crawford & Semlitsch in review). This habitat degradation and alteration most likely causes a reduction in the amount of microhabitat available and forces smaller salamanders into a choice of suboptimal microhabitat or increasing predation risk in more suitable microhabitats (Crawford & Semlitsch 2007). Either of these choices likely results in decreased abundances and salamanders being found closer to streams (Crawford & Semlitsch 2007; Crawford & Semlitsch in review).

Microhabitat selection in many species of stream salamanders is mediated by a number of complex factors including environmental variables, competition, and

predation. Alteration of habitats likely results in increased competition and predation rates and subsequent population declines, so it is imperative to mitigate the effects of practices such as even-aged timber harvesting. Other studies have suggested that even-aged timber harvesting is not the most appropriate method to maintain viable amphibian populations and alternative uneven-aged harvesting techniques (e.g., selective harvesting) would conserve these populations (Grialou et al. 2000, Karraker & Welsh Jr. 2006). However, these studies only address populations at the local level and do not discuss the implications at the landscape level. If only 5-10% of the landscape was logged using even-aged timber harvest methods versus the entire landscape being logged using uneven-aged timber harvest, it is likely that the even-aged timber harvest method would be more successful in conserving salamanders at the landscape level. By reducing the loss of leaf litter, soil moisture and overall canopy cover, declines of stream salamander assemblages can be kept to a minimum.

In addition to investigating alternative harvesting techniques (and their impacts), we would recommend implementing more stringent buffer zone criteria around streams of all types. Current U.S. Forest Service guidelines for southern Appalachian streams require only an ~ 9 m (30 feet) buffer for headwater through second-order streams and an ~ 30 m (100 feet) buffer for streams third-order and above. Crawford and Semlitsch (2007) found that stream salamander assemblages require a core terrestrial habitat of 42.6 m and recommended a total buffer zone of 92.6 m (core terrestrial habitat plus a 50 m buffer to mitigate edge effects). While current USFS regulations are not adequate to protect stream salamander populations in clearcuts, these larger buffer zones would likely

decrease the impact of timber harvesting on microhabitats within riparian areas of streams and help prevent local population declines.

Although there is increasing research on microhabitat use in amphibians in the past decade, there remains a gap in our knowledge on the microhabitat use in stream-breeding salamanders and how this influences overall abundance and diversity at the landscape level. In order to mitigate the impacts of habitat alteration, it is necessary to have a clear understanding of the role of both abiotic and biotic factors play in determining microhabitat use and abundance. We have identified important factors in structuring these assemblages and hope our work stimulates future research on the mechanisms of selection, costs and benefits, links to population declines, and conservation solutions.

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**Table 1.** Environmental variables for plots in which stream salamanders were not captured and plots in which stream salamanders were captured in riparian areas.

<i>Environmental Variables<sup>a</sup></i>	<i>Salamanders</i>	
	<i>Present</i>	<i>Absent</i>
Leaf Litter Depth (mm)	31.27 (0.43)	25.12 (0.28)
Soil Temperature (°C)	18.27 (0.15)	18.87 (0.11)
Soil Moisture (%)	45.68 (0.85)	34.44 (0.50)
Canopy Cover (%)	91.47 (0.24)	89.67 (0.29)

<sup>a</sup>*Mean and standard error values.*

**Table 2.** Environmental variables for plots in which seal salamanders were not captured and plots in which seal salamanders were captured in riparian areas.

<i>Environmental Variables<sup>a</sup></i>	<i>Salamanders</i>	
	<i>Present</i>	<i>Absent</i>
Leaf Litter Depth (mm)	30.15 (0.90)	25.12 (0.28)
Soil Temperature (°C)	18.35 (0.35)	18.87 (0.11)
Soil Moisture (%)	43.35 (2.22)	34.44 (0.50)
Canopy Cover (%)	91.70 (0.38)	89.67 (0.29)

<sup>a</sup>*Mean and standard error values.*

**Table 3.** Environmental variables for plots in which Ocoee salamanders were not captured and plots in which Ocoee salamanders were captured in riparian areas.

<i>Environmental Variables<sup>a</sup></i>	<i>Salamanders</i>	
	<i>Present</i>	<i>Absent</i>
Leaf Litter Depth (mm)	30.48 (0.54)	25.12 (0.28)
Soil Temperature (°C)	17.70 (0.19)	18.87 (0.11)
Soil Moisture (%)	46.45 (1.15)	34.44 (0.50)
Canopy Cover (%)	91.47 (0.26)	89.67 (0.29)

<sup>a</sup>*Mean and standard error values.*

**Table 4.** Environmental variables for plots in which two-lined salamanders were not captured and plots in which two-lined salamanders were captured in riparian areas.

<i>Environmental Variables<sup>a</sup></i>	<i>Salamanders</i>	
	<i>Present</i>	<i>Absent</i>
Leaf Litter Depth (mm)	34.31 (1.01)	25.12 (0.28)
Soil Temperature (°C)	19.61 (0.28)	18.87 (0.11)
Soil Moisture (%)	45.82 (1.38)	34.44 (0.50)
Canopy Cover (%)	91.19 (0.76)	89.67 (0.29)

<sup>a</sup>*Mean and standard error values.*

**Table 5.** *A priori* regression models explaining the influence of environmental variables on stream salamander abundance in headwater streams in the Nantahala National Forest, North Carolina. Model rankings were based on Akaike’s Information Criterion corrected for small sample size ( $AIC_c$ ). The global model fits the data ( $\chi^2 = 213.107$ ,  $df = 9$ ,  $P < 0.001$ ,  $n = 336$ ).

<i>Model<sup>a</sup></i>	<i>(-2Loglike)</i>	<i>K<sup>b</sup></i>	<i>AIC<sub>c</sub></i>	<i>ΔAIC<sub>c</sub><sup>c</sup></i>	<i>ω<sub>i</sub><sup>d</sup></i>
Global	556.05	10	576.73	0.00	1.00
Gradient	605.87	3	611.94	35.22	0.00
Microhabitat	611.01	4	619.13	42.41	0.00
Distance	636.52	2	640.56	63.83	0.00
Forage	661.39	3	667.46	90.73	0.00
Soil	666.37	3	672.44	95.71	0.00
Moisture	704.74	2	708.77	132.05	0.00
Leaf	713.19	2	717.22	140.49	0.00
Canopy	742.41	2	746.44	169.72	0.00
Macrohabitat	741.64	4	749.77	173.04	0.00
Temperature	757.49	2	761.53	184.80	0.00
Site	765.97	2	770.00	193.28	0.00
Null	769.16	1	771.17	194.44	0.00
Slope	768.43	2	772.47	195.74	0.00
Period	769.09	2	773.13	196.40	0.00
Elevation	769.14	2	773.18	196.45	0.00

<sup>a</sup>*Model names correspond to models given in the methods section.*

<sup>b</sup>*Number of estimable parameters in approximating model.*

<sup>c</sup>*Difference in value between  $AIC_c$  of the current model versus the best-approximating model.*

<sup>d</sup>*Akaike weight. Probability that the current model (i) is the best-approximating model among those tested.*

**Table 6.**  $\beta$  estimates and 95% confidence intervals for parameters in the *a priori* Global model for stream salamander abundance. The Global model includes nine environmental variables.

<i>Parameter</i>	$\beta$	<i>Lower 95% C.I.</i>	<i>Upper 95% C.I.</i>
Intercept	-0.075	-4.130	3.979
Site	0.005	-0.051	0.060
Period	-0.051	-0.357	0.255
Distance	-0.043	-0.059	-0.027
Leaf	0.082	0.054	0.109
Temperature	-0.147	-0.254	-0.040
Moisture	0.038	0.025	0.051
Canopy	-0.002	-0.041	0.037
Slope	-0.010	-0.040	0.019
Elevation	-0.001	-0.002	0.001

**Table 7.** Post-hoc regression models (including the four best *a priori* models) explaining the influence of environmental variables on stream salamander abundance in headwater streams in the Nantahala National Forest, North Carolina. Model rankings were based on Akaike’s Information Criterion corrected for small sample size ( $AIC_c$ ). The global model fits the data ( $\chi^2 = 213.107$ ,  $df = 9$ ,  $P < 0.001$ ,  $n = 336$ ).

<i>Model<sup>a</sup></i>	<i>(-2Loglike)</i>	<i>K<sup>b</sup></i>	<i>AIC<sub>c</sub></i>	<i>ΔAIC<sub>c</sub><sup>c</sup></i>	<i>ω<sub>i</sub><sup>d</sup></i>
DistLeafMoisTemp	557.76	5	567.94	0.00	0.99
Global	556.05	10	576.73	8.78	0.01
DistLeafMois	573.41	4	581.53	13.58	0.00
DistLeafTemp	592.74	4	600.86	32.91	0.00
DistLeaf	597.18	3	603.26	35.31	0.00
Gradient	605.87	3	611.94	44.00	0.00
Microhabitat	611.01	4	619.13	51.19	0.00
Distance	636.52	2	640.56	72.62	0.00
DistTemp	635.92	3	642.00	74.05	0.00
TempLeaf	686.26	3	692.33	124.39	0.00

<sup>a</sup>*Model names correspond to models given in the methods section.*

<sup>b</sup>*Number of estimable parameters in approximating model.*

<sup>c</sup>*Difference in value between  $AIC_c$  of the current model versus the best-approximating model.*

<sup>d</sup>*Akaike weight. Probability that the current model (i) is the best-approximating model among those tested.*

**Table 8.** *A priori* regression models explaining the influence of environmental variables on seal salamander abundance in headwater streams in the Nantahala National Forest, North Carolina. Model rankings were based on Akaike's Information Criterion corrected for small sample size ( $AIC_c$ ). The global model fits the data ( $\chi^2 = 69.888$ ,  $df = 9$ ,  $P < 0.001$ ,  $n = 336$ ).

<i>Model<sup>a</sup></i>	<i>(-2Loglike)</i>	<i>K<sup>b</sup></i>	<i>AIC<sub>c</sub></i>	<i>ΔAIC<sub>c</sub><sup>c</sup></i>	<i>ω<sub>i</sub><sup>d</sup></i>
Gradient	21.322	3	219.29	0.00	0.60
Distance	216.35	2	220.39	1.10	0.35
Global	203.46	10	224.14	4.85	0.05
Microhabitat	246.36	4	254.48	35.19	0.00
Forage	254.91	3	260.99	41.70	0.00
Soil	255.40	3	261.47	42.18	0.00
Moisture	262.02	2	266.05	46.76	0.00
Leaf	263.93	2	267.96	48.67	0.00
Canopy	266.25	2	270.28	50.99	0.00
Macrohabitat	262.85	4	270.97	51.68	0.00
Slope	271.02	2	275.06	55.77	0.00
Null	273.35	1	275.36	56.07	0.00
Temp	271.35	2	275.38	56.09	0.00
Elevation	271.87	2	275.91	56.62	0.00
Site	273.02	2	277.05	57.76	0.00
Period	273.31	2	277.35	58.06	0.00

<sup>a</sup>*Model names correspond to models given in the methods section.*

<sup>b</sup>*Number of estimable parameters in approximating model.*

<sup>c</sup>*Difference in value between  $AIC_c$  of the current model versus the best-approximating model.*

<sup>d</sup>*Akaike weight. Probability that the current model (i) is the best-approximating model among those tested.*

**Table 9.**  $\beta$  estimates and 95% confidence intervals for parameters in the *a priori* Global model for seal salamander abundance. The Global model includes nine environmental variables.

<i>Parameter</i>	$\beta$	<i>Lower 95% C.I.</i>	<i>Upper 95% C.I.</i>
Intercept	-3.157	-12.385	6.070
Site	0.071	-0.035	0.177
Period	-0.152	-0.859	0.555
Distance	-0.150	-0.225	-0.076
Leaf	0.062	0.003	0.122
Temperature	-0.050	-0.290	0.190
Moisture	0.027	-0.005	0.059
Canopy	0.021	-0.067	0.110
Slope	0.022	-0.042	0.086
Elevation	-0.002	-0.005	0.001

**Table 10.** Post-hoc regression models (including the four best *a priori* models) explaining the influence of environmental variables on seal salamander abundance in headwater streams in the Nantahala National Forest, North Carolina. Model rankings were based on Akaike's Information Criterion corrected for small sample size ( $AIC_c$ ). The global model fits the data ( $\chi^2 = 69.888$ ,  $df = 9$ ,  $P < 0.001$ ,  $n = 336$ ).

<i>Model<sup>a</sup></i>	<i>(-2Loglike)</i>	<i>K<sup>b</sup></i>	<i>AIC<sub>c</sub></i>	<i>ΔAIC<sub>c</sub><sup>c</sup></i>	<i>ω<sub>i</sub><sup>d</sup></i>
DistLeaf	210.17	3	216.25	0.00	0.32
DistLeafMois	208.20	4	216.32	0.08	0.31
DistLeafMoisTemp	208.07	5	218.26	2.01	0.12
DistLeafTemp	210.16	4	218.28	2.04	0.12
Gradient	213.22	3	219.29	3.02	0.07
Distance	216.35	2	220.39	4.14	0.04
DistTemp	216.24	3	222.31	6.06	0.02
Global	203.46	10	224.14	7.89	0.01
Microhabitat	246.36	4	254.48	38.24	0.00
TempLeaf	259.46	3	265.46	49.22	0.00

<sup>a</sup>*Model names correspond to models given in the methods section.*

<sup>b</sup>*Number of estimable parameters in approximating model.*

<sup>c</sup>*Difference in value between  $AIC_c$  of the current model versus the best-approximating model.*

<sup>d</sup>*Akaike weight. Probability that the current model (i) is the best-approximating model among those tested.*

**Table 11.** *A priori* regression models explaining the influence of environmental variables on Ocoee salamander abundance in headwater streams in the Nantahala National Forest, North Carolina. Model rankings were based on Akaike’s Information Criterion corrected for small sample size ( $AIC_c$ ). The global model fits the data ( $\chi^2 = 191.212$ ,  $df = 9$ ,  $P < 0.001$ ,  $n = 336$ ).

<i>Model<sup>a</sup></i>	<i>(-2Loglike)</i>	<i>K<sup>b</sup></i>	<i>AIC<sub>c</sub></i>	<i>ΔAIC<sub>c</sub><sup>c</sup></i>	<i>ω<sub>i</sub><sup>d</sup></i>
Global	348.54	10	369.22	0.00	1.00
Gradient	381.15	3	387.23	18.01	0.00
Distance	399.03	2	403.06	33.84	0.00
Microhabitat	419.36	4	427.48	58.26	0.00
Soil	442.03	3	448.10	78.88	0.00
Forage	481.83	3	487.90	118.68	0.00
Moisture	495.55	2	499.59	130.37	0.00
Temperature	517.44	2	521.48	152.26	0.00
Leaf	519.54	2	523.57	154.35	0.00
Canopy	528.24	2	532.28	163.06	0.00
Macrohabitat	526.62	4	534.74	165.52	0.00
Null	539.75	1	541.77	172.55	0.00
Elevation	537.93	2	541.96	172.74	0.00
Site	539.03	2	543.07	173.85	0.00
Period	539.07	2	543.10	173.88	0.00
Slope	539.13	2	543.16	173.94	0.00

<sup>a</sup>*Model names correspond to models given in the methods section.*

<sup>b</sup>*Number of estimable parameters in approximating model.*

<sup>c</sup>*Difference in value between  $AIC_c$  of the current model versus the best-approximating model.*

<sup>d</sup>*Akaike weight. Probability that the current model (i) is the best-approximating model among those tested.*

**Table 12.**  $\beta$  estimates and 95% confidence intervals for parameters in the *a priori* Global model for Ocoee salamander abundance. The Global model includes nine environmental variables.

<i>Parameter</i>	$\beta$	<i>Lower 95% C.I.</i>	<i>Upper 95% C.I.</i>
Intercept	1.784	-3.318	6.886
Site	-0.016	-0.108	0.076
Period	-0.087	-0.517	0.343
Distance	-0.123	-0.167	-0.079
Leaf	0.064	0.025	0.104
Temperature	-0.204	-0.371	-0.037
Moisture	0.047	0.030	0.065
Canopy	-0.014	-0.061	0.032
Slope	-0.043	-0.086	0.000
Elevation	0.000	-0.002	0.003

**Table 13.** Post-hoc regression models (including the four best *a priori* models)

explaining the influence of environmental variables on Ocoee salamander abundance in headwater streams in the Nantahala National Forest, North Carolina. Model rankings were based on Akaike's Information Criterion corrected for small sample size ( $AIC_c$ ).

The global model fits the data ( $\chi^2 = 191.212$ ,  $df = 9$ ,  $P < 0.001$ ,  $n = 336$ ).

<i>Model<sup>a</sup></i>	<i>(-2Loglike)</i>	<i>K<sup>b</sup></i>	<i>AIC<sub>c</sub></i>	<i>ΔAIC<sub>c</sub><sup>c</sup></i>	<i>ω<sub>i</sub><sup>d</sup></i>
DistLeafMoisTemp	353.49	5	363.67	0.00	0.94
Global	348.54	10	369.22	5.55	0.06
DistLeafMois	372.38	4	380.50	16.83	0.00
DistLeafTemp	378.64	4	386.76	23.09	0.00
Gradient	381.15	3	387.23	23.55	0.00
DistLeaf	386.23	3	392.31	28.63	0.00
DistTemp	393.82	3	399.89	36.22	0.00
Distance	399.03	2	403.06	39.39	0.00
Microhabitat	419.36	4	427.48	63.81	0.00
TempLeaf	483.59	3	489.66	125.99	0.00

<sup>a</sup>*Model names correspond to models given in the methods section.*

<sup>b</sup>*Number of estimable parameters in approximating model.*

<sup>c</sup>*Difference in value between  $AIC_c$  of the current model versus the best-approximating model.*

<sup>d</sup>*Akaike weight. Probability that the current model (i) is the best-approximating model among those tested.*

**Table 14.** *A priori* regression models explaining the influence of environmental variables on two-lined salamander abundance in headwater streams in the Nantahala National Forest, North Carolina. Model rankings were based on Akaike's Information Criterion corrected for small sample size ( $AIC_c$ ). The global model fits the data ( $\chi^2 = 44.598$ ,  $df = 9$ ,  $P < 0.001$ ,  $n = 336$ ).

<i>Model<sup>a</sup></i>	<i>(-2Loglike)</i>	<i>K<sup>b</sup></i>	<i>AIC<sub>c</sub></i>	<i>ΔAIC<sub>c</sub><sup>c</sup></i>	<i>ω<sub>i</sub><sup>d</sup></i>
Forage	246.55	3	252.62	0.00	0.51
Microhabitat	244.91	4	253.03	0.41	0.41
Leaf	252.70	2	256.74	4.12	0.07
Global	239.60	10	260.27	7.65	0.01
Soil	272.07	3	278.14	25.52	0.00
Moisture	275.22	2	279.26	26.64	0.00
Period	276.02	2	280.06	27.43	0.00
Gradient	274.10	3	280.18	27.55	0.00
Canopy	276.18	2	280.22	27.60	0.00
Temperature	278.16	2	282.19	29.57	0.00
Macrohabitat	275.00	4	283.12	30.50	0.00
Distance	281.04	2	285.08	32.45	0.00
Site	281.81	2	285.85	33.22	0.00
Null	284.19	1	286.21	33.85	0.00
Elevation	283.69	2	287.73	35.11	0.00
Slope	283.79	2	287.83	35.20	0.00

<sup>a</sup>*Model names correspond to models given in the methods section.*

<sup>b</sup>*Number of estimable parameters in approximating model.*

<sup>c</sup>*Difference in value between  $AIC_c$  of the current model versus the best-approximating model.*

<sup>d</sup>*Akaike weight. Probability that the current model (i) is the best-approximating model among those tested.*

**Table 15.**  $\beta$  estimates and 95% confidence intervals for parameters in the *a priori* Global model for two-lined salamander abundance. The Global model includes nine environmental variables.

<i>Parameter</i>	$\beta$	<i>Lower 95% C.I.</i>	<i>Upper 95% C.I.</i>
Intercept	-13.666	-23.529	-3.802
Site	-0.023	-0.136	0.090
Period	0.460	-0.190	1.111
Distance	-0.003	-0.017	0.012
Leaf	0.130	0.075	0.186
Temperature	0.063	-0.146	0.273
Moisture	0.009	-0.022	0.039
Canopy	0.060	-0.038	0.158
Slope	-0.010	-0.069	0.050
Elevation	0.000	-0.003	0.003

**Table 16.** Post-hoc regression models (including the four best *a priori* models) explaining the influence of environmental variables on two-lined salamander abundance in headwater streams in the Nantahala National Forest, North Carolina. Model rankings were based on Akaike's Information Criterion corrected for small sample size ( $AIC_c$ ). The global model fits the data ( $\chi^2 = 44.598$ ,  $df = 9$ ,  $P < 0.001$ ,  $n = 336$ ).

<i>Model<sup>a</sup></i>	<i>(-2Loglike)</i>	<i>K<sup>b</sup></i>	<i>AIC<sub>c</sub></i>	<i>ΔAIC<sub>c</sub><sup>c</sup></i>	<i>ω<sub>i</sub><sup>d</sup></i>
Forage	246.55	3	252.62	0.00	0.32
Microhabitat	244.91	4	253.03	0.41	0.26
DistLeafMois	246.51	4	254.63	2.01	0.12
DistLeafMoisTemp	244.47	5	254.65	2.03	0.12
TempLeaf	250.07	3	256.14	3.52	0.06
DistLeafTemp	248.31	4	256.43	3.80	0.05
Leaf	252.70	2	256.74	4.12	0.04
DistLeaf	252.05	3	258.13	5.50	0.02
Global	239.60	10	260.27	7.65	0.01
DistTemp	271.83	3	277.90	25.28	0.00

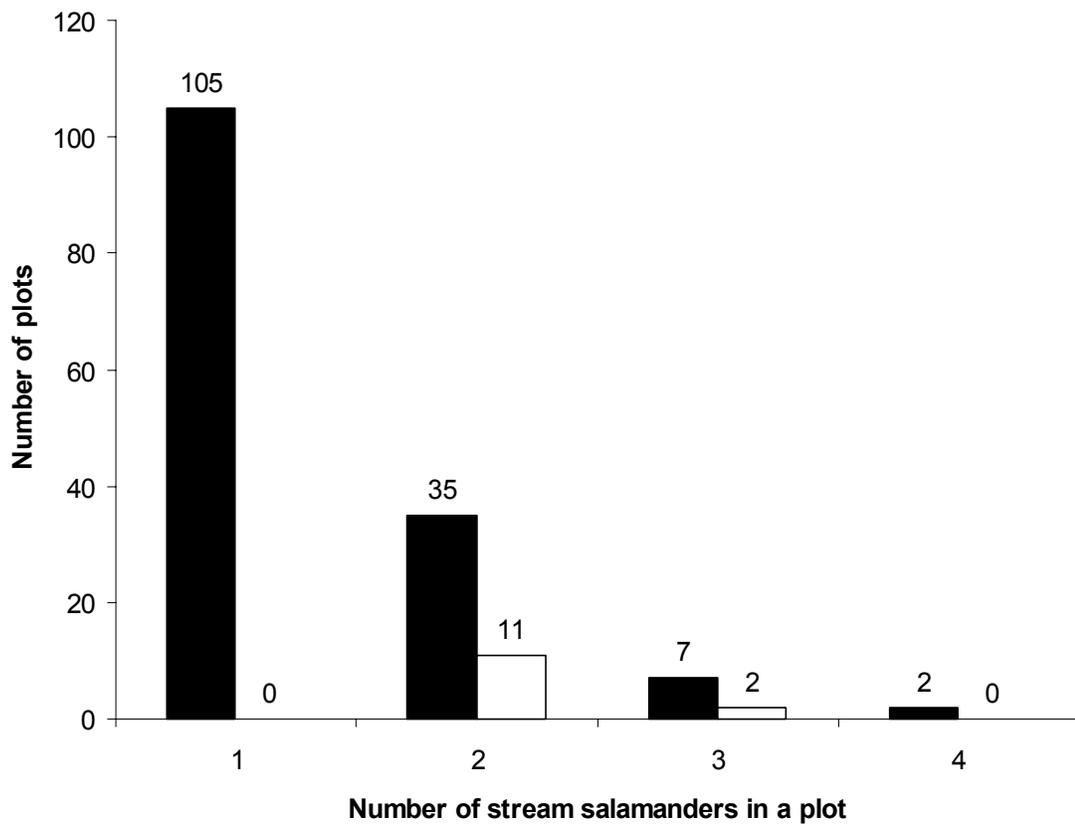
<sup>a</sup>*Model names correspond to models given in the methods section.*

<sup>b</sup>*Number of estimable parameters in approximating model.*

<sup>c</sup>*Difference in value between  $AIC_c$  of the current model versus the best-approximating model.*

<sup>d</sup>*Akaike weight. Probability that the current model (i) is the best-approximating model among those tested.*

**Figure 1.** Total number of plots stream salamanders were captured in among the riparian area of headwater streams in the Nantahala National Forest, North Carolina (black bars represent total number of plots in which salamanders were captured, white bars represent number of plots in which salamanders of two or more species were captured).



## Chapter 4

### POST-DISTURBANCE EFFECTS OF EVEN-AGED TIMBER HARVEST ON STREAM SALAMANDERS IN SOUTHERN APPALACHIAN FORESTS

John A. Crawford and Raymond D. Semlitsch

#### **Abstract**

Habitat degradation and fragmentation has received increased attention in the past 15 years as a primary factor responsible for the decline of many species of wildlife including amphibians. A number of studies have begun to address the impacts of forest management practices such as even-aged timber harvest on amphibian populations. In the eastern United States many of the studies have focused on fully terrestrial plethodontid salamanders, while information on stream-breeding plethodontids remains relatively lacking. Using two different survey methods (area-constrained daytime searches and nighttime visual encounter searches), we estimated mean core terrestrial habitat and abundance for stream-breeding salamanders in three different tree stand age classes in southern Appalachian streams from May to August 2005. We found that overall stream salamander abundance and core terrestrial habitat use was reduced in stands less than 40 years of age compared to stands 41-80 years old, and greater than 81 years old. The decreased abundance and core terrestrial habitat use was accompanied by a decrease in leaf litter depth, soil moisture, and canopy cover. Regression analyses using an information theoretic approach (AIC) showed that distance from the stream

and leaf litter depth was the best predictor of stream salamander abundance. The Blue Ridge two-lined salamander (*Eurycea wilderae*) was the most affected salamander in the assemblage and we conservatively estimate at least a 40 year recovery period for the assemblage to return to pre-disturbance levels. To protect stream amphibians, alternative silvicultural practices such as uneven-aged timber harvest (e.g., selective harvesting) must be considered as well as application of more stringent riparian buffer zone widths.

## **Introduction**

The current biodiversity crisis has received a great deal of attention over the past two decades. As of 2006, the World Conservation Union (IUCN) found that of 40,177 species assessed using IUCN Red List criteria, 16,199 are now listed as threatened with extinction (IUCN 2006). They found that one out of every eight bird species, one out of every four mammal species, and one out of every three species of amphibians was at risk of extinction (IUCN 2006). This follows the findings of Stuart et al. (2004), who indicated that amphibians are far more threatened than either birds or mammals. While a number of factors have been attributed to the decline of amphibians (e.g., chemical pollution, disease, global climate change, introduction of exotic species), habitat loss and degradation are generally accepted as the main cause of this decline (Wake 1998; Carey et al. 1999; Semlitsch 2000; Cushman 2006). Amphibians are especially sensitive to loss and degradation of habitat due to their unique life history requirements (i.e., most amphibians require both aquatic and terrestrial resources to complete their life cycle).

Habitat loss and degradation can result from a number of processes (e.g., land development, agriculture). Within the past decade a number of studies have examined the impacts of timber harvesting on wildlife populations (e.g., Gram et al. 2003; Constantine et al. 2004; Goldstein et al. 2005) and on ecosystem processes (e.g., Ash 1995; Swank et al. 2001; Wilkerson et al. 2006) in the United States. In the Pacific Northwest redwood forests, Ashton et al. (2006) found that species richness and relative abundance of stream amphibians were significantly greater in the late-seral forests (unharvested) compared to mid-seral forests (37-60 yrs post-harvest). In the Ozark region of the Midwest, Herbeck and Larsen (1999) found that terrestrial salamander density was lowest in recently harvested forests ( $\leq 5$  yrs post-harvest) and highest in old-growth forests ( $> 120$  yrs). Comparison of recently harvested forests ( $\leq 5$  yrs) with second growth mature forests ( $> 70$  yrs post-harvest) showed that terrestrial salamanders were reduced to very low numbers when mature forests were harvested (Herbeck & Larsen 1999). Both studies indicate that it could take at least 60 years for amphibian assemblages to return to pre-harvest levels.

In the eastern part of the United States, the effects of timber harvesting have focused on a specific family of salamanders (Plethodontidae). Plethodontid salamanders make up an important ecological component of many forested ecosystems and often exceed the combined biomass of other terrestrial vertebrates throughout the Appalachian Mountain region (Burton & Likens 1975; Hairston 1987; Petranka & Murray 2001). There has been considerable debate as to the long-term impacts and recovery of plethodontid salamander populations as a result of even-aged timber harvesting in the southern Appalachian Mountain region (Ash & Pollock 1999). Petranka et al. (1993)

found that mean abundance of salamanders was approximately five times higher in mature forests (> 50 yrs old) versus forests that were recently clearcut (< 10 yrs old). They estimated that it would take 50-70 years for salamander populations to return to pre-disturbance levels. In contrast, Ash (1997) found that abundance of salamanders on clearcut plots decreased to approximately 30-50% of forested plots in the first year after timber harvest and were almost zero after the second year. However, he found that salamanders returned to clearcut plots 4-6 years post-disturbance and estimated that it would take 20-24 years for salamander populations to return to pre-disturbance levels. Despite this considerable work in the eastern United States, the majority of this research has focused on woodland salamanders (e.g., Petranka et al. 1993; Ash 1997; Harper & Guynn Jr. 1999). However, all woodland salamanders are completely terrestrial, have direct development, and do not require water for reproduction, which means they are not constrained to terrestrial areas near streams. Yet, most species of the Plethodontidae require streams for reproduction and larval development, but the effects of timber harvesting on these salamanders remains an area in need of investigation.

We sampled stream salamanders in three different stand-age categories to determine the effects of post-disturbance timber harvest and estimate recovery time of salamander populations. Specifically, we compared core habitat use and salamander abundance in riparian areas found in three stand age-classes. Based on previous studies of plethodontids, we hypothesized that core habitat use and salamander abundance would be significantly lower in stands < 40 years old compared to stands between the ages 41-80 years and stands > 81 years.

## **Methods**

### Study Area

To estimate core terrestrial habitat use (Crawford & Semlitsch 2007) and stream salamander abundance, we sampled riparian forests adjacent to 12 headwater streams in the southern Appalachian Mountains, Nantahala National Forest, Macon County, North Carolina (U.S.A.). All sites were located between 771-1221 m in elevation and were located at least 1 km apart (Table 1). Four streams were located in stands between 0-40 years since last timber harvest, four streams were located in stands between 41-80 years since last timber harvest, and four streams were located in stands that had not been harvested for  $\geq 81$  years. To ensure maximum capture success and detection of rare species (Hyde & Simons 2001), we used two different sampling techniques. Sites were sampled six times each (three day transects, three night transects) from May to August of 2005.

### Daytime Sampling

During day transects, we sampled a paired transect that was separated by 1 m (to increase sample sizes of salamanders; data for each plot were combined) and extended perpendicular from the stream bank into the adjacent forest. Monitoring stations were established at 1, 3, 7, 10, 15, 25, 50, and 100 m from the stream bank, based on the home range sizes and potential distances traveled by the target species of stream-breeding salamanders (Crawford & Semlitsch 2007). At each stream, we conducted the three daytime transects by using area-constrained searches of each plot ( $2 \times 2.25 \text{ m}^2$  or  $4.5 \text{ m}^2$  per station) by sifting through leaf litter and coarse woody debris at each monitoring

station for an average of 10 minutes. At each plot, data was collected on four environmental variables: 1) Leaf litter depth – measured three times in each plot (6 times per station) using a hand ruler for an average leaf litter depth value; 2) Soil temperature – measured three times in each plot (6 times per station) using an infrared Raytek® MT4 temperature gun for an average temperature value; 3) Soil moisture – measured three times in each plot (6 times per station) using an Aquaterr® M300 soil moisture meter for an average soil moisture value; and 4) Canopy cover – measured one time in each plot (2 times per station) using a spherical crown densiometer for an average canopy cover value.

We identified all salamanders to species, weighed and measured for snout-vent length and total length, determined sex, and recorded the distance from the stream. We released all salamanders at the site of capture. We determined age class (adult or juvenile) by comparing measured snout-vent lengths of each individual to published size classes for each species (Petranka 1998).

### Nighttime Sampling

We used a visual encounter search (VES) during the three night transects to capture surface-active salamanders. Two researchers walked a straight line that was perpendicular from the stream edge (defined as the edge of the streambed) out to 100 m and recorded distance from the stream edge for each salamander encountered. While walking the perpendicular transect, each researcher searched 2.5 m to the right and left of the transect line. We processed salamanders in the nighttime samples the same as detailed above for the daytime samples.

## Data Analysis

We used a one-way ANOVA to test for treatment effects of stand age-classes on mean core habitat use and salamander abundance (response variables) using the comparison of means model in SPSS (v. 15). Tukey's honestly significant difference test was used to test for differences among age-classes. Tests with  $p < 0.05$  were considered significant.

To investigate the relationships between daytime stream salamander abundance and daytime environmental variables, we used an information-theoretic approach to model selection (Burnham and Anderson 2002). The information-theoretic approach allows one to select a "best" model and to rank the remaining models (Burnham and Anderson 2002). Burnham and Anderson (2002) suggest the information-theoretic approach should be used in observational studies where other hypothesis testing methods may lead to "data dredging" and over-fitted models. Using 8 environmental variables, we built 19 *a priori* models to test hypotheses predicting stream salamander abundance. The environmental variables we selected (and subsequent models we built) were based on previous studies detailing their importance to plethodontid salamanders as well as pilot data collected during the 2003 field season. The predictive models are: (1) Null (intercept only); (2) Site (site location); (3) Period (sampling period); (4) Distance (distance from the stream); (5) Leaf (leaf litter depth); (6) Temperature (soil temperature); (7) Moisture (soil moisture); (8) Canopy (canopy cover); (9) Age (stand age); (10) Soil (soil moisture and soil temperature); (11) Forage (soil moisture and leaf litter depth); (12) Gradient (soil moisture and distance from the stream); (13) DistLeaf (distance from the stream and leaf litter depth); (14) DistAge (distance from the stream and stand age); (15) DistMoisLeaf (distance from the stream, soil moisture, and leaf litter

depth); (16) Microhabitat (soil moisture, soil temperature, and leaf litter depth); (17) DistAgeLeaf (distance from the stream, stand age, and leaf litter depth); (18) DistMoisLeafAge (distance from the stream, soil moisture, leaf litter depth, and stand age); and (19) Global (site, period, distance from the stream, leaf litter depth, soil temperature, soil moisture, canopy cover, and stand age).

For each model, we calculated the AIC value corrected for small sample sizes ( $AIC_c$ ), which is a measure of model fit adjusted for the number of parameters (Burnham and Anderson 2002).  $AIC_c$  values were derived from loglinear regressions with a poisson distribution using the generalized linear model in SPSS (v. 15). We ranked all candidate models according to their  $AIC_c$  values, and the best model had the smallest  $AIC_c$  value (Burnham and Anderson 2002). We also calculated  $\Delta AIC_c$ , which is the difference in AIC between each model and the best model in the set. AIC differences less than two are considered to indicate little difference between models, while differences of 4-7 indicate considerably less support for the model with the higher AIC value although it may have some empirical support (Burnham and Anderson 2002). Lastly, we calculated Akaike weights ( $\omega_i$ ) to determine the weight of evidence in favor of each model and to estimate the relative importance of each individual parameter (Burnham and Anderson 2002).

## **Results**

### Daytime Salamander Sampling

In 2005, 148 total salamanders were captured among the 12 different stands during daytime sampling. We captured 34 seal salamanders (*Desmognathus monticola*), 66

Ocoee salamanders (*D. ocoee*), and 48 Blue Ridge two-lined salamanders (*Eurycea wilderae*). Stream salamander abundance was 5.03 salamanders/transect ( $\pm 0.24$  SE) in stands  $\geq 81$  years of age, 5.08 salamanders/transect ( $\pm 0.43$  SE) in stands between 41-80 years of age, and 2.17 salamanders/transect ( $\pm 0.21$  SE) in stands  $\leq 40$  years of age (Figure 1). Stream salamander abundance was reduced in stands  $\leq 40$  years of age compared to stands between the ages of 41-80 years, and stands  $\geq 81$  years old. There was no apparent difference between stands of the three different age classes for seal salamanders or Ocoee salamanders (Figure 1). Abundance of two-lined salamanders was 1.68 salamanders/transect ( $\pm 0.42$  SE) in stands  $\geq 81$  years of age, 1.75 salamanders/transect ( $\pm 0.17$  SE) in stands between 41-80 years of age, and 0.58 salamanders/transect ( $\pm 0.17$  SE) in stands  $\leq 40$  years of age (Figure 1). Two-lined salamander abundance was reduced in stands  $\leq 40$  years of age compared to stands between the ages of 41-80 years, and stands  $\geq 81$  years old.

As monitoring distance increased from the stream edge, the abundance of stream salamanders decreased relatively rapidly in stands  $\leq 40$  years of age, while the decrease in abundance in stands between 41-80 years was much less severe, and abundance remained relatively stable in stands  $\geq 81$  years of age (Table 2). There were no apparent differences in abundance between the stands in the first three monitoring stations (1, 3, and 7 m), however abundances were much lower in the remaining monitoring stations (10, 15, 25, and 50 m) in stands  $\leq 40$  years of age (Table 2).

Stream salamanders were found an average of 3.4 m ( $\pm 0.6$  SE) from the stream in stands  $\leq 40$  years of age, 10.3 m ( $\pm 1.1$  SE) from the stream in stands between 41-80 years of age, and 12.2 m ( $\pm 0.6$  SE) in stands  $\geq 81$  years of age (Table 3). Average

distance from the stream was significantly less in stands  $\leq 40$  years old compared to stands between 41-80 years old, and stands  $\geq 81$  years old ( $F = 34.46$ ,  $df = 11$ ,  $p < 0.001$ ; Table 3). There was no significant difference between stands of the three different age classes for seal salamanders or Ocoee salamanders ( $F = 3.32$ ,  $df = 11$ ,  $p = 0.083$ ;  $F = 2.47$ ,  $df = 11$ ,  $p = 0.14$ , respectively; Table 3). Average distance from the stream for two-lined salamanders was 6.1 m ( $\pm 1.6$  SE) in stands  $\leq 40$  years of age, 19.6 m ( $\pm 0.9$  SE) in stands between 41-80 years of age, and 22.1 m ( $\pm 2.7$  SE) in stands  $\geq 81$  years of age (Table 3). Average distance from the stream for two-lined salamanders was significantly less in stands  $\leq 40$  years of age compared to stands between the ages of 41-80 years, and stands  $\geq 81$  years old ( $F = 21.38$ ,  $df = 11$ ,  $p < 0.001$ ; Table 3).

Average leaf litter depth, average soil moisture, and average canopy cover in stands  $\leq 40$  years of age were all lower compared to stands between the ages of 41-80 years, and stands  $\geq 81$  years (Table 4). There was no apparent difference of average soil temperature between the different stand age classes (Table 4). As distance increased from the stream, soil temperatures remained relatively constant in the three different stand age classes, whereas leaf litter depth increased slightly (Figure 2). Soil moisture showed a slight decrease as distance from the stream increased between the three different stand age classes. Canopy cover remained relatively constant as distance from the stream increased in stands  $\leq 40$  years of age, but showed a slight decrease in stands between 41-80 years of age and stands  $\geq 80$  years of age.

Of the 19 *a priori* regression models, the DistLeaf model and the DistAgeLeaf model best predicted the abundance of stream salamanders (Table 5). The only variables for which the estimate of beta had a confidence interval that did not overlap zero were

distance from the stream and leaf litter depth (Table 6). The best *a priori* models for predicting seal salamander abundance were the DistAge model that included both distance from the stream and stand age and the DistLeaf model that included distance from the stream and leaf litter depth (Table 7). The only variable for which the estimate of beta had a confidence interval that did not overlap zero was distance from the stream (Table 8). The best *a priori* models for predicting Ocoee salamander abundance were the DistLeaf model that included both distance from the stream and leaf litter depth and the DistAgeLeaf model that included distance from the stream, stand age, and leaf litter depth (Table 9). The only variable for which the estimate of beta had a confidence interval that did not overlap zero was distance from the stream (Table 10). The best *a priori* models for predicting two-lined salamander abundance were the DistLeaf model that included both distance from the stream and leaf litter depth and the DistAgeLeaf model that included distance from the stream, stand age, and leaf litter depth (Table 11). The only variables for which the estimate of beta had a confidence interval that did not overlap zero were distance from the stream and leaf litter depth (Table 12).

#### Nighttime Salamander Sampling

During the 2005 field season, 473 total salamanders were captured among the 12 different stands during nighttime sampling. We captured 108 seal salamanders (*Desmognathus monticola*), 167 Ocoee salamanders (*D. ocoee*), and 198 Blue Ridge two-lined salamanders (*Eurycea wilderae*). Stream salamander abundance was 17.9 salamanders/transect ( $\pm 2.08$  SE) in stands  $\geq 81$  years of age, 14.6 salamanders/transect ( $\pm 1.09$  SE) in stands between 41-80 years of age, and 6.83 salamanders/transect ( $\pm 0.51$

SE) in stands  $\leq 40$  years of age (Figure 3). Stream salamander abundance was significantly lower in stands  $\leq 40$  years of age compared to stands between the ages of 41-80 years, and stands  $\geq 81$  years old ( $F = 16.87$ ,  $df = 11$ ,  $p = 0.001$ ). There was no significant difference between stands of the three different age classes for seal salamanders or Ocoee salamanders ( $F = 2.08$ ,  $df = 11$ ,  $p = 0.181$ ;  $F = 2.02$ ,  $df = 11$ ,  $p = 0.188$ , respectively; Figure 3). Abundance of two-lined salamanders was 7.77 salamanders/transect ( $\pm 0.64$  SE) in stands  $\geq 81$  years of age, 6.35 salamanders/transect ( $\pm 0.20$  SE) in stands between 41-80 years of age, and 2.40 salamanders/transect ( $\pm 0.21$  SE) in stands  $\leq 40$  years of age (Figure 3). Two-lined salamander abundance was significantly lower in stands  $\leq 40$  years of age compared to stands between the ages of 41-80 years, and stands  $\geq 81$  years old ( $F = 47.33$ ,  $df = 11$ ,  $p < 0.001$ ).

Stream salamanders were found an average of 9.5 m ( $\pm 0.7$  SE) from the stream in stands  $\leq 40$  years of age, 21.2 m ( $\pm 1.9$  SE) from the stream in stands between 41-80 years of age, and 21.8 m ( $\pm 1.9$  SE) in stands  $\geq 81$  years of age (Table 13). Average distance from the stream was significantly less in stands  $\leq 40$  years old compared to stands between 41-80 years old, and stands  $\geq 81$  years old ( $F = 18.27$ ,  $df = 11$ ,  $p = 0.001$ ; Table 6). Average distances from the stream for seal salamanders, Ocoee salamanders, and two-lined salamanders were significantly less in stands  $\leq 40$  years of age compared to stands between the ages of 41-80 years, and stands  $\geq 81$  years old ( $F = 10.15$ ,  $df = 11$ ,  $p = 0.005$ ;  $F = 8.02$ ,  $df = 11$ ,  $p = 0.01$ ;  $F = 50.27$ ,  $df = 11$ ,  $p < 0.001$ , respectively; Table 13).

## **Discussion**

Most stream-breeding salamanders are highly philopatric, long-lived, and usually exist in relatively stable populations (Hairston 1987). These life history traits make them reliable indicators of potential biotic diversity in stream and riparian ecosystems, and their relative abundance and core habitat use can be a critical indicator of stream and riparian ecosystem health (Welsh Jr. & Ollivier 1998; Crawford & Semlitsch 2007). In eastern United States forests, salamanders typically comprise the greatest biomass of any vertebrates (Burton & Likens 1975; Petranka & Murray 2001) and serve a key role in the ecosystem because they consume invertebrates and serve as prey for other vertebrates. Determining the long-term impacts of timber harvest on stream salamander core terrestrial habitat use and abundance is critical in maintaining existing populations and developing methods to ameliorate the impacts of timber harvest in the future.

A number of studies have documented the importance of factors such as canopy cover, leaf litter availability, and soil parameters in the abundance and distribution of plethodontid salamanders (Spotila 1972; Ash 1997; Harper & Guynn Jr. 1999; Hicks & Pearson 2003; McKenny et al. 2006). Lungless salamanders in the family Plethodontidae are even more dependent on moist habitats for dermal respiration than other families of amphibians (Petranka 1998). In the southern Appalachian Mountains, clear-cutting of forests results in reduced litter dry mass (amount of leaf litter), leaf litter depth, and leaf litter moisture (Ash 1995). Timber harvest can also degrade habitat for salamanders because the elimination of canopy cover can result in increased soil temperature and decreased surface soil moisture (Petranka et al. 1994; Ash 1997; Herbeck & Larsen 1999; Crawford & Semlitsch unpubl. data). We found that leaf litter depth, soil moisture, and

canopy cover were all reduced in stands  $\leq 40$  years of age when compared to stands between the ages of 41-80 years, and stands  $\geq 81$  years of age. Leaf litter depth was vastly different in the stands that were  $\leq 40$  years of age (Figure 2). Additionally, our regression analyses revealed that the leaf litter depth and distance from the stream were the two most important predictors of stream salamander abundance. In northern hardwoods, Covington (1981) found that “forest floor organic matter” declined 55% over the first 15 years after logging. Reduction in leaf litter depth and leaf litter moisture was also reported by Ash (1995) and Buckner and Shure (1985) following clearcutting in southern Appalachian forests.

We found that overall abundances of stream salamanders sampled both during the day and night were reduced in stands  $\leq 40$  years of age when compared to the older stand age classes. While there were no significant reductions in the number of seal salamanders or Ocoee salamanders, there were significantly fewer Blue Ridge two-lined salamanders in the youngest stands ( $\leq 40$  years old) in both day and night transects. A number of factors could account for this difference among species. Regression analyses revealed that distance from the stream was important for all three species of stream salamanders, but leaf litter depth was also important for the two-lined salamanders. Two-lined salamanders are relatively small and slender salamanders ( $< 110$  mm total length). Their body size leads to an increased surface area:volume ratio and higher risk of water loss than the other larger species of salamanders (Spotila 1972). These salamanders forage for invertebrates in the leaf litter and when this leaf litter becomes thinner, drier, or both it is unlikely they will have the moisture necessary to carry on dermal respiration. Additionally, with a reduction in leaf litter, adequate populations of invertebrate prey

may not be present (Ash 1995). With a decrease in leaf litter and available space, competition with other species will likely increase for invertebrate prey.

The amount of core terrestrial habitat used by the stream salamanders in our stands between 41-80 years of age, and stands  $\geq 81$  years old was similar to values found by Crawford and Semlitsch (2007) in mature forests that were  $\geq 80$  years old. We found that core terrestrial habitat was significantly reduced in stands  $\leq 40$  years of age for the entire assemblage. It was reduced for two-lined salamanders during daytime sampling and for all three species (seal salamanders, Ocoee salamanders, and two-lined salamanders) during nighttime sampling. This reduction in amount of core terrestrial habitat used by the stream salamanders is likely related to the reduced habitat quality (loss of leaf litter depth and moisture) resulting from the timber harvest. The decrease in the amount of suitable core terrestrial habitat results in the decreased abundance of stream salamanders in the stands less than 40 years of age. The decrease in core terrestrial habitat use by two-lined salamanders is especially important in terms of salamander abundance. Crawford and Semlitsch (2007) showed that the majority of dusky salamanders (*Desmognathus* spp.) are found within 15 m of the stream's edge, whereas two-lined salamanders occurred beyond 20 m of the stream's edge. This was likely due to competition and predation from the larger dusky salamanders. In stands  $\leq 40$  years of age, the two-lined salamanders are being forced closer to the stream which likely results in greater competition and predation pressures from the larger dusky salamanders and a subsequent decline in population number.

While the seal salamanders and Ocoee salamanders seemed to be only marginally affected by stand age, the two-lined salamanders were greatly affected. The two-lined

salamanders seem to be the most sensitive species to the disturbance and take the longest period of time to recover in the assemblage. We estimate that it would take at least 40 years for the entire assemblage to recover to pre-disturbance levels. This estimate falls within the range of values that have been found for other plethodontid salamanders in the southern Appalachian Mountains (Petranka et al. 1993; Ash 1997; Hicks & Pearson 2003).

Although timber harvest will continue, there are techniques to mitigate the effects of the harvest on stream salamander populations. Selective harvesting techniques such as thinning and group selection have become more common. Harpole and Haas (1999) found that abundance of salamanders was lower after harvest on group selection, shelterwood, and leave-tree treatments, but understory removal had no effect. Messere and Ducey (1998) found no differences in red-backed salamander (*Plethodon cinereus*) density between gaps created by selective harvesting. Other studies have suggested that even-aged timber harvesting is not the most appropriate method to maintain viable amphibian populations and alternative uneven-aged harvesting techniques (e.g., selective harvesting) would conserve these populations (Grialou et al. 2000, Karraker & Welsh Jr. 2006). While these studies are on fully terrestrial plethodontids, our results indicate the same conclusion is possibly true for stream-breeding plethodontids. By reducing the loss of leaf litter and overall canopy cover, declines of stream salamander assemblages can be kept to a minimum. Marsh et al. (2004) found that colonization of forested areas declined with increased distance from these areas for red-backed salamanders. Considering the limited dispersal capability of plethodontid salamanders, a timber harvest plan that rotated cut times and sites along streams might be most successful in mitigating

local population declines. We would suggest cutting blocks of forest on alternating sides of the stream once every 40 years to ensure that appropriate habitat remains for the salamanders. In addition to investigating alternative harvesting techniques (and their impacts), we would recommend implementing more stringent buffer zone criteria around streams of all types. Current U.S. Forest Service guidelines for southern Appalachian streams require only an ~ 9 m (30 feet) buffer for headwater through second-order streams and an ~ 30 m (100 feet) buffer for streams third-order and above. Crawford and Semlitsch (2007) found that stream salamander assemblages require a core terrestrial habitat of 42.6 m and recommended a total buffer zone of 92.6 m (core terrestrial habitat and a 50 m buffer for edge effects). Thus, current USFS regulations would not be adequate to protect stream salamander populations in clearcuts and likely result in local population declines, especially two-lined salamanders.

Even though a plethora of research on the impacts of even-aged timber harvest has been done over the past 10 years on terrestrial plethodontid salamanders, there remains a serious lack of understanding on the impacts of forest management on stream-breeding salamanders, especially the mechanisms of change. We have provided estimates of the timber harvest impacts on stream salamander abundance and core terrestrial habitat use as well as a conservative estimate of the return time of assemblages to pre-disturbance levels. If we accept that salamanders are critical indicators of ecosystem health and function, we hope our research stimulates future work on forestry management practices, mechanisms of change, variation among species or life stages, impacts on the long-term persistence of amphibian populations, and maintenance of Appalachian biodiversity.

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**Table 1.** Stand age characteristics of stream sites used in the Nantahala National Forest, North Carolina.

<i>Locality (UTM)</i>	<i>Stream Order</i>	<i>Harvest Year</i>	<i>Stand Acreage</i>
17S 0295856 3876196	Headwater	1974	28
17S 0302755 3875984	Headwater	1978	42
17S 0304584 3879244	Headwater	1980	40
17S 0295062 3877269	Headwater	1979	109
17S 0301579 3879720	Headwater	1927	25
17S 0306599 3876345	Headwater	1938	46
17S 0293270 3877227	Headwater	1939	82
17S 0297120 3886701	Headwater	1943	30
17S 0301777 3876563	Headwater	1911	137
17S 0301518 3881167	Headwater	1897	36
17S 0295745 3876672	Headwater	1921	30
17S 0297841 3885457	Headwater	1906	42

**Table 2.** Daytime abundance of stream salamanders as a function of distance from the stream in three different stand age classes.

<i>Station distance from stream<sup>a</sup></i>	<i>Stand Age (yrs)</i>		
	<i>0-40</i>	<i>41-80</i>	<i>80+</i>
1	1.0, 0.12	1.07, 0.30	0.5, 0.22
3	0.68, 0.24	1.32, 0.14	0.98, 0.24
7	0.33, 0.14	0.58, 0.25	1.0, 0.17
10	0.15, 0.09	0.85, 0.15	0.58, 0.17
15	0.0	0.55, 0.25	0.83, 0.21
25	0.0	0.33, 0.14	0.9, 0.21
50	0.0	0.3, 0.0	0.15, 0.09
100	0.0	0.0	0.0

<sup>a</sup>*Mean and standard error values.*

**Table 3.** Summary of daytime occurrence distances<sup>a</sup> (m) from stream edge of a stream salamander assemblage in the southern Appalachian Mountains in three different stand age classes.<sup>b</sup>

<i>Species</i> <sup>c</sup>	<i>Stand Age (yrs)</i>			<i>ANOVA</i>	
	<i>0-40</i>	<i>41-80</i>	<i>80+</i>	F	p
Stream Total	3.4 <sup>a</sup> , 5.2 n = 26	10.3 <sup>b</sup> , 12.1 n = 61	12.2 <sup>b</sup> , 14.0 n = 61	34.46	<0.001
Stream Adults	3.7 <sup>a</sup> , 6.0 n = 16	11.9 <sup>b</sup> , 14.2 n = 39	13.2 <sup>b</sup> , 15.5 n = 42	25.72	<0.001
Stream Juveniles	2.8 <sup>a</sup> , 6.3 n = 10	7.5 <sup>ab</sup> , 10.9 n = 22	10.8 <sup>b</sup> , 14.2 n = 18	6.94	0.015
<i>D. monticola</i> Total	2.5, 5.0 n = 7	4.4, 6.9 n = 12	6.5, 9.0 n = 15	3.32	0.083
<i>D. monticola</i> Adults	2.3, 7.6 n = 3	6.0, 10.5 n = 6	7.0, 11.5 n = 11	1.27	0.331
<i>D. monticola</i> Juveniles	2.7, 8.7 n = 4	3.4, 9.5 n = 6	4.8, 10.9 n = 4	0.20	0.825
<i>D. ocoee</i> Total	3.2, 6.3 n = 12	5.4, 8.6 n = 28	7.5, 10.7 n = 26	2.47	0.14
<i>D. ocoee</i> Adults	2.5, 7.0 n = 8	5.6, 9.5 n = 16	6.4, 10.3 n = 16	1.20	0.35
<i>D. ocoee</i> Juveniles	2.5, 7.4 n = 4	4.0, 8.9 n = 12	8.1, 12.3 n = 10	2.33	0.17

<i>E. wilderae</i> Total	6.1 <sup>a</sup> , 10.3 n = 7	19.6 <sup>b</sup> , 23.9 n = 21	22.1 <sup>b</sup> , 26.3 n = 20	21.38	<0.001
<i>E. wilderae</i> Adults	6.8 <sup>a</sup> , 12.7 n = 5	21.0 <sup>b</sup> , 27.0 n = 17	22.1 <sup>b</sup> , 28.1 n = 16	10.55	0.004
<i>E. wilderae</i> Juveniles	1.3 <sup>a</sup> , 10.6 n = 2	20.0 <sup>b</sup> , 29.3 n = 4	21.2 <sup>b</sup> , 29.3 n = 4	8.57	0.013

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<sup>a</sup>Distance encompassing 50% and 95% of the population, respectively.

<sup>b</sup>Means with the same letter within rows were not significantly different (Tukey HSD multiple comparison,  $p < 0.05$ ).

<sup>c</sup>Stream denotes salamanders in the assemblage (Desmognathus monticola, Desmognathus ocoee, and Eurycea wilderae).

**Table 4.** Environmental variables for riparian areas in three different stand age classes.

<i>Environmental Variables<sup>a</sup></i>	<i>Stand Age (yrs)</i>		
	<i>0-40</i>	<i>41-80</i>	<i>80+</i>
Leaf Litter Depth (mm)	13.2, 0.6	27.9, 0.9	26.9, 0.8
Soil Temperature (°C)	19.0, 0.7	17.0, 0.7	17.7, 1.2
Soil Moisture (%)	40.6, 0.4	42.7, 0.4	43.1, 0.4
Canopy Cover (%)	89.7, 0.2	91.5, 0.5	91.6, 0.2

<sup>a</sup>*Mean and standard error values.*

**Table 5.** *A priori* regression models explaining the influence of environmental variables on stream salamander abundance in headwater streams in the Nantahala National Forest, North Carolina. Model rankings were based on Akaike's Information Criterion corrected for small sample size ( $AIC_c$ ). The global model fits the data ( $\chi^2 = 87.672$ ,  $df = 8$ ,  $P < 0.001$ ,  $n = 288$ ).

<i>Model<sup>a</sup></i>	<i>(-2Loglike)</i>	<i>K<sup>b</sup></i>	<i>AIC<sub>c</sub></i>	<i>ΔAIC<sub>c</sub><sup>c</sup></i>	<i>ω<sub>i</sub><sup>d</sup></i>
DistLeaf	475.78	3	481.86	0.00	0.36
DistAgeLeaf	473.85	4	481.99	0.13	0.33
DistMoisLeaf	475.54	4	483.69	1.82	0.14
DistMoisAgeLeaf	473.81	5	484.02	2.16	0.12
DistAge	480.11	3	486.20	4.33	0.04
Global	470.96	10	489.61	7.75	0.01
Distance	492.71	2	496.75	14.89	0.00
Gradient	491.64	3	497.73	15.87	0.00
Forage	529.27	3	535.36	53.50	0.00
Microhabitat	528.90	4	537.04	55.18	0.00
Moisture	533.60	2	537.64	55.79	0.00
Soil	533.53	3	539.61	57.75	0.00
Age	546.04	2	550.08	68.13	0.00
Canopy	552.00	2	556.05	74.18	0.00
Leaf	554.45	2	558.49	76.63	0.00
Site	555.79	2	559.83	77.97	0.00
Null	558.63	1	560.65	78.79	0.00

Period	556.63	2	560.67	78.81	0.00
Temp	557.67	2	561.71	79.85	0.00

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<sup>a</sup>*Model names correspond to models given in the methods section.*

<sup>b</sup>*Number of estimable parameters in approximating model.*

<sup>c</sup>*Difference in value between  $AIC_c$  of the current model versus the best-approximating model.*

<sup>d</sup>*Akaike weight. Probability that the current model (i) is the best-approximating model among those tested.*

**Table 6.**  $\beta$  estimates and 95% confidence intervals for parameters in the *a priori* Global model for stream salamander abundance. The Global model includes eight environmental variables.

<i>Parameter</i>	$\beta$	<i>Lower 95% C.I.</i>	<i>Upper 95% C.I.</i>
Intercept	-0.371	-6.428	5.687
Site	0.004	-0.065	0.073
Period	0.181	-0.223	0.585
Distance	-0.044	-0.062	-0.027
Leaf	0.034	0.008	0.059
Temperature	-0.004	-0.117	0.109
Moisture	0.013	-0.026	0.051
Canopy	-0.018	-0.082	0.046
Age	0.005	-0.003	0.013

**Table 7.** *A priori* regression models explaining the influence of environmental variables on seal salamander abundance in headwater streams in the Nantahala National Forest, North Carolina. Model rankings were based on Akaike's Information Criterion corrected for small sample size ( $AIC_c$ ). The global model fits the data ( $\chi^2 = 39.522$ ,  $df = 8$ ,  $P < 0.001$ ,  $n = 288$ ).

<i>Model<sup>a</sup></i>	<i>(-2Loglike)</i>	<i>K<sup>b</sup></i>	<i>AIC<sub>c</sub></i>	<i>ΔAIC<sub>c</sub><sup>c</sup></i>	<i>ω<sub>i</sub><sup>d</sup></i>
DistAge	191.60	3	197.68	0.00	0.27
DistLeaf	192.01	3	198.09	0.41	0.22
Distance	194.58	2	198.62	0.93	0.17
DistAgeLeaf	191.09	4	199.23	1.55	0.13
DistMoisLeaf	192.01	4	200.15	2.46	0.08
Gradient	194.51	3	200.59	2.91	0.06
DistMoisAgeLeaf	191.02	5	201.24	3.55	0.05
Global	184.72	10	203.37	5.69	0.02
Moisture	214.65	2	218.69	21.01	0.00
Soil	213.70	3	219.79	22.10	0.00
Forage	214.65	3	220.74	23.05	0.00
Microhabitat	213.67	4	221.81	24.13	0.00
Canopy	220.30	2	224.34	26.66	0.00
Age	221.21	2	225.26	27.57	0.00
Period	221.56	2	225.56	27.88	0.00
Null	224.24	1	226.26	28.57	0.00
Site	223.94	2	227.99	30.30	0.00

Temp	224.21	2	228.26	30.57	0.00
Leaf	224.24	2	228.28	30.60	0.00

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<sup>a</sup>*Model names correspond to models given in the methods section.*

<sup>b</sup>*Number of estimable parameters in approximating model.*

<sup>c</sup>*Difference in value between  $AIC_c$  of the current model versus the best-approximating model.*

<sup>d</sup>*Akaike weight. Probability that the current model (i) is the best-approximating model among those tested.*

**Table 8.**  $\beta$  estimates and 95% confidence intervals for parameters in the *a priori* Global model for seal salamander abundance. The Global model includes eight environmental variables.

<i>Parameter</i>	$\beta$	<i>Lower 95% C.I.</i>	<i>Upper 95% C.I.</i>
Intercept	-3.079	-15.012	8.854
Site	0.138	-0.008	0.284
Period	0.825	-0.076	1.727
Distance	-0.080	-0.141	-0.020
Leaf	0.024	-0.033	0.080
Temperature	-0.144	-0.392	0.104
Moisture	0.022	-0.056	0.101
Canopy	-0.003	-0.129	0.123
Age	0.009	-0.007	0.025

**Table 9.** *A priori* regression models explaining the influence of environmental variables on Ocoee salamander abundance in headwater streams in the Nantahala National Forest, North Carolina. Model rankings were based on Akaike's Information Criterion corrected for small sample size ( $AIC_c$ ). The global model fits the data ( $\chi^2 = 70.001$ ,  $df = 8$ ,  $P < 0.001$ ,  $n = 288$ ).

<i>Model<sup>a</sup></i>	<i>(-2Loglike)</i>	<i>K<sup>b</sup></i>	<i>AIC<sub>c</sub></i>	<i>ΔAIC<sub>c</sub><sup>c</sup></i>	<i>ω<sub>i</sub><sup>d</sup></i>
DistLeaf	281.42	3	287.51	0.00	0.38
DistAgeLeaf	280.59	4	288.73	1.22	0.20
DistAge	283.14	3	289.22	1.72	0.16
DistMoisLeaf	281.41	4	289.55	2.04	0.14
DistMoisAgeLeaf	280.49	5	290.70	3.19	0.08
Distance	288.36	2	292.40	4.89	0.03
Gradient	288.21	3	294.30	6.79	0.01
Global	278.49	10	297.136	9.63	0.00
Moisture	328.61	2	332.65	45.15	0.00
Forage	328.55	3	334.64	47.13	0.00
Soil	328.59	3	334.68	47.17	0.00
Microhabitat	328.52	4	336.66	49.15	0.00
Age	343.16	2	347.21	59.70	0.00
Canopy	344.05	2	348.10	60.59	0.00
Site	345.63	2	349.68	62.17	0.00
Null	348.49	1	350.50	63.00	0.00
Period	347.36	2	351.40	63.89	0.00

Temp	347.55	2	351.59	64.09	0.00
Leaf	348.45	2	352.59	64.99	0.00

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<sup>a</sup>*Model names correspond to models given in the methods section.*

<sup>b</sup>*Number of estimable parameters in approximating model.*

<sup>c</sup>*Difference in value between  $AIC_c$  of the current model versus the best-approximating model.*

<sup>d</sup>*Akaike weight. Probability that the current model (i) is the best-approximating model among those tested.*

**Table 10.**  $\beta$  estimates and 95% confidence intervals for parameters in the *a priori* Global model for Ocoee salamander abundance. The Global model includes eight environmental variables.

<i>Parameter</i>	$\beta$	<i>Lower 95% C.I.</i>	<i>Upper 95% C.I.</i>
Intercept	1.062	-8.043	10.167
Site	-0.035	-0.142	0.072
Period	0.068	-0.561	0.697
Distance	-0.115	-0.170	-0.061
Leaf	0.033	-0.009	0.074
Temperature	0.033	-0.143	0.209
Moisture	0.001	-0.059	0.061
Canopy	-0.033	-0.130	0.064
Age	0.005	-0.006	0.017

**Table 11.** *A priori* regression models explaining the influence of environmental variables on two-lined salamander abundance in headwater streams in the Nantahala National Forest, North Carolina. Model rankings were based on Akaike's Information Criterion corrected for small sample size ( $AIC_c$ ). The global model fits the data ( $\chi^2 = 21.055$ ,  $df = 8$ ,  $P = 0.007$ ,  $n = 288$ ).

<i>Model<sup>a</sup></i>	<i>(-2Loglike)</i>	<i>K<sup>b</sup></i>	<i>AIC<sub>c</sub></i>	<i>ΔAIC<sub>c</sub><sup>c</sup></i>	<i>ω<sub>i</sub><sup>d</sup></i>
DistLeaf	245.89	3	251.97	0.00	0.49
DistAgeLeaf	245.69	4	253.83	1.86	0.20
DistMoisLeaf	245.86	4	254.01	2.04	0.18
DistMoisAgeLeaf	245.68	5	255.90	3.92	0.07
Leaf	253.68	2	257.72	5.75	0.03
Forage	252.18	3	258.27	6.30	0.02
Microhabitat	252.04	4	260.18	8.21	0.01
Global	244.93	10	263.58	11.61	0.00
DistAge	258.05	3	264.13	12.16	0.00
Distance	261.95	2	265.99	14.02	0.00
Age	262.08	2	266.12	14.15	0.00
Site	263.66	2	267.70	15.73	0.00
Gradient	261.86	3	267.94	15.97	0.00
Null	265.98	1	268.00	16.03	0.00
Moisture	264.44	2	268.49	16.51	0.00
Temperature	264.55	2	268.60	16.62	0.00
Soil	263.57	3	269.66	17.68	0.00

Canopy	265.62	2	269.67	17.69	0.00
Period	265.85	2	269.90	17.92	0.00

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<sup>a</sup>*Model names correspond to models given in the methods section.*

<sup>b</sup>*Number of estimable parameters in approximating model.*

<sup>c</sup>*Difference in value between  $AIC_c$  of the current model versus the best-approximating model.*

<sup>d</sup>*Akaike weight. Probability that the current model (i) is the best-approximating model among those tested.*

**Table 12.**  $\beta$  estimates and 95% confidence intervals for parameters in the *a priori* Global model for two-lined salamander abundance. The Global model includes eight environmental variables.

<i>Parameter</i>	$\beta$	<i>Lower 95% C.I.</i>	<i>Upper 95% C.I.</i>
Intercept	-0.165	-11.509	11.180
Site	-0.030	-0.148	0.088
Period	-0.223	-0.930	0.484
Distance	-0.019	-0.035	-0.003
Leaf	0.080	0.035	0.125
Temperature	0.050	-0.142	0.243
Moisture	-0.004	-0.072	0.064
Canopy	-0.035	-0.154	0.085
Age	-0.003	-0.017	0.012

**Table 13.** Summary of nighttime occurrence distances<sup>a</sup> (m) from stream edge of a stream salamander assemblage in the southern Appalachian Mountains in three different stand age classes.<sup>b</sup>

<i>Species</i> <sup>c</sup>	<i>Stand Age (yrs)</i>			<i>ANOVA</i>	
	<i>0-40</i>	<i>41-80</i>	<i>80+</i>	F	p
Stream Total	9.5 <sup>a</sup> , 13.1 n = 82	21.2 <sup>b</sup> , 24.9 n = 176	21.8 <sup>b</sup> , 25.5 n = 215	18.27	0.001
Stream Adults	10.0 <sup>a</sup> , 13.6 n = 52	22.3 <sup>b</sup> , 25.9 n = 127	24.0 <sup>b</sup> , 27.6 n = 136	22.63	<0.001
Stream Juveniles	8.5, 15.6 n = 30	18.4, 25.5 n = 49	18.2, 25.3 n = 79	3.28	0.085
<i>D. monticola</i> Total	2.3 <sup>a</sup> , 3.6 n = 18	5.6 <sup>b</sup> , 7.0 n = 40	5.6 <sup>b</sup> , 6.9 n = 50	10.15	0.005
<i>D. monticola</i> Adults	2.2 <sup>a</sup> , 3.4 n = 10	6.1 <sup>b</sup> , 7.3 n = 29	7.1 <sup>b</sup> , 8.2 n = 27	26.01	<0.001
<i>D. monticola</i> Juveniles	2.5, 4.3 n = 8	4.1, 5.9 n = 11	4.1, 5.9 n = 23	1.30	0.320
<i>D. ocoee</i> Total	4.0 <sup>a</sup> , 5.6 n = 35	7.6 <sup>b</sup> , 9.2 n = 60	7.5 <sup>b</sup> , 9.2 n = 72	8.02	0.010
<i>D. ocoee</i> Adults	3.8 <sup>a</sup> , 5.6 n = 24	8.3 <sup>b</sup> , 10.0 n = 42	7.8 <sup>b</sup> , 9.5 n = 47	10.17	0.005
<i>D. ocoee</i> Juveniles	4.3, 6.5 n = 11	6.2, 8.4 n = 18	7.2, 9.5 n = 25	2.23	0.163

<i>E. wilderae</i> Total	20.3 <sup>a</sup> , 23.9 n = 29	39.4 <sup>b</sup> , 43.0 n = 76	40.4 <sup>b</sup> , 44.0 n = 93	50.27 <0.001
<i>E. wilderae</i> Adults	21.2 <sup>a</sup> , 28.7 n = 18	40.5 <sup>b</sup> , 47.9 n = 56	45.1 <sup>b</sup> , 52.6 n = 62	14.98 0.001
<i>E. wilderae</i> Juveniles	17.1 <sup>a</sup> , 29.1 n = 11	34.6 <sup>ab</sup> , 46.7 n = 20	38.2 <sup>b</sup> , 50.3 n = 31	4.546 0.043

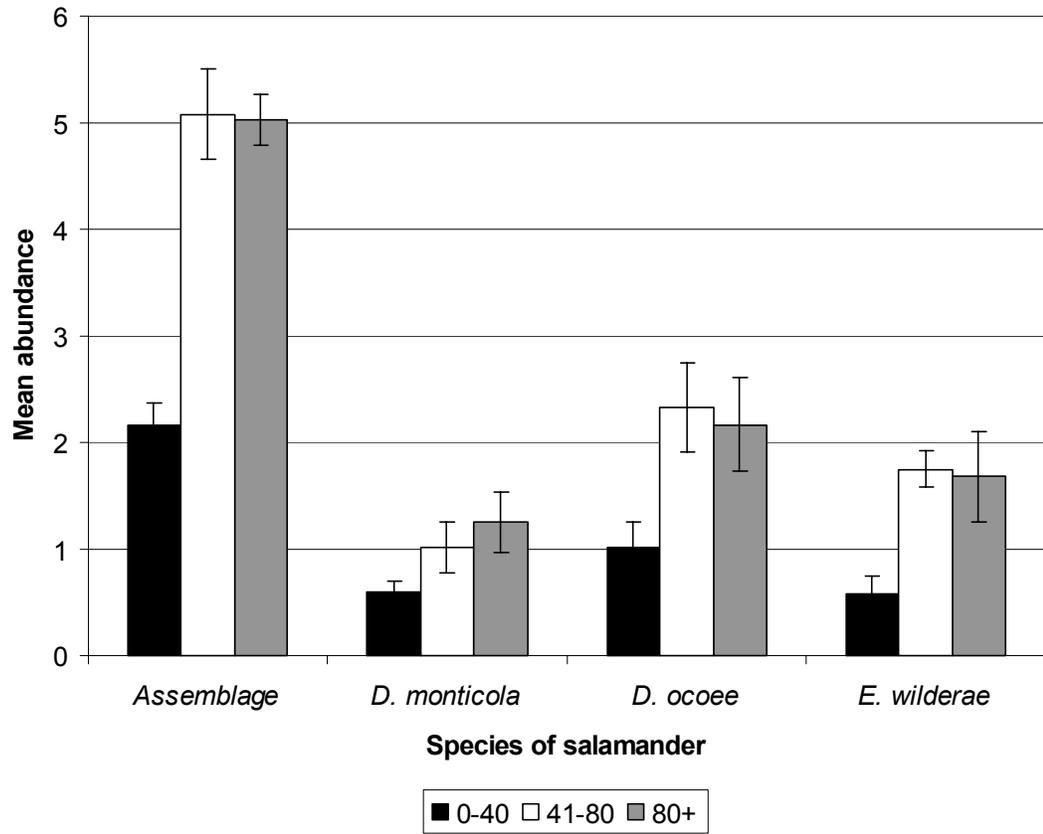
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<sup>a</sup>Distance encompassing 50% and 95% of the population, respectively.

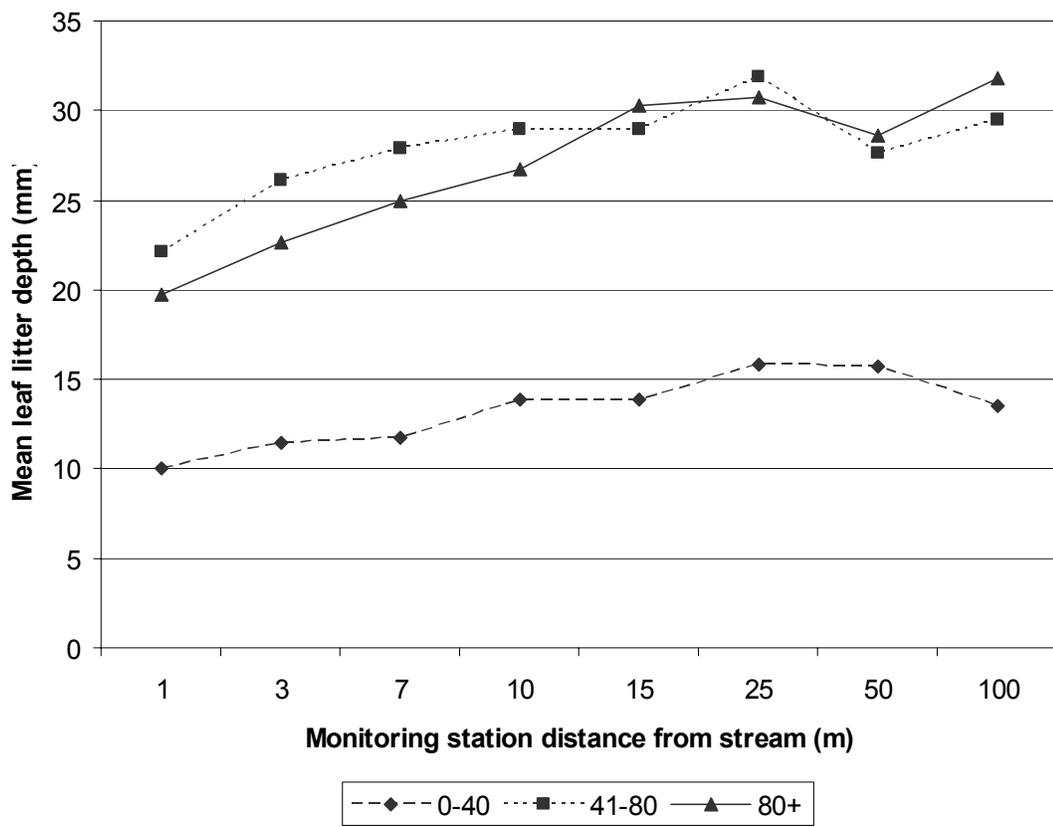
<sup>b</sup>Means with the same letter within rows were not significantly different (Tukey HSD multiple comparison,  $p < 0.05$ ).

<sup>c</sup>Stream denotes salamanders in the assemblage (Desmognathus monticola, Desmognathus ocoee, and Eurycea wilderae).

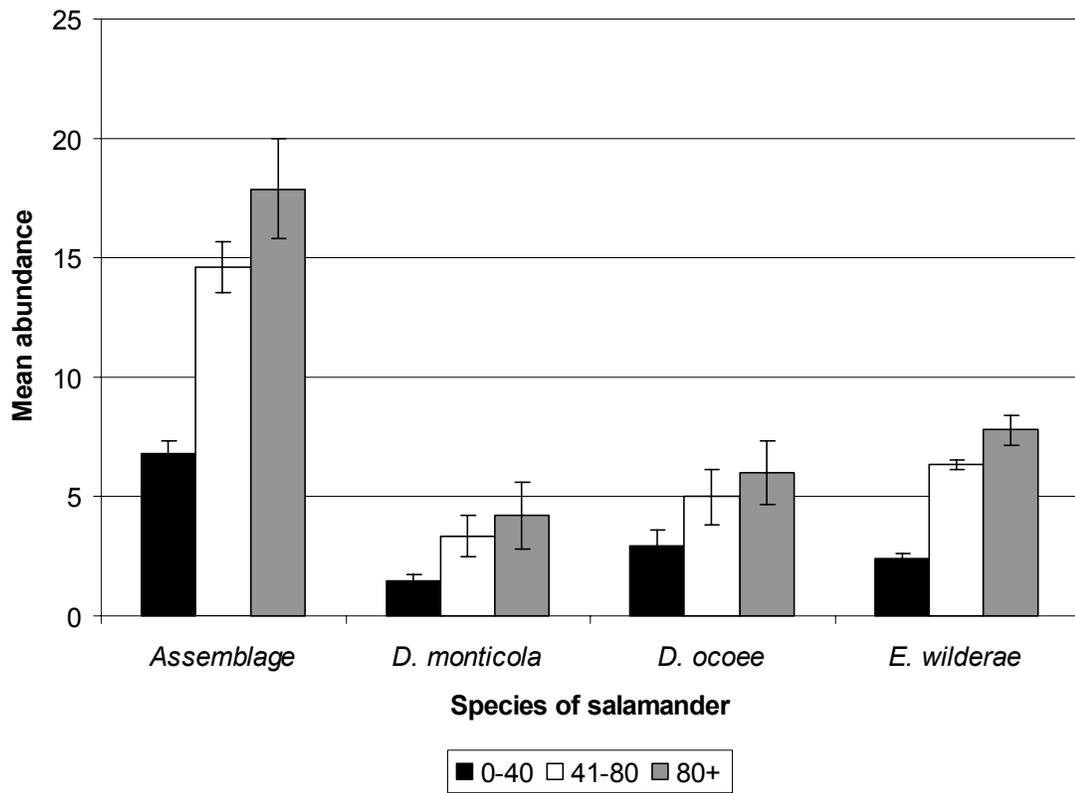
**Figure 1.** Stream salamander abundance (mean  $\pm$  SE) from the edges of headwater streams in three different stand age classes in the Nantahala National Forest, North Carolina (based on daytime transect searches).



**Figure 2.** Mean leaf litter depth at each daytime monitoring station from the edges of headwater streams in three different stand age classes in the Nantahala National Forest, North Carolina.



**Figure 3.** Stream salamander abundance (mean  $\pm$  SE) from the edges of headwater streams in three different stand age classes in the Nantahala National Forest, North Carolina (based on nighttime transect searches).



## Chapter 5

### TRADE-OFF BETWEEN DESICCATION AND PREDATION RISK IN THE BLUE RIDGE TWO-LINED SALAMANDER (*EURYCEA WILDERAE*)

John A. Crawford

#### **Abstract**

With increased attention on amphibian declines in the past decade, many agree the primary factor responsible for this decline is habitat fragmentation and degradation. A number of studies have begun to address the impacts of forest management practices on amphibian populations. However, behavioral responses of amphibians to forestry practices such as logging are still lacking. Using a laboratory experiment, I investigated the behavioral choice of Blue Ridge two-lined salamanders (*Eurycea wilderae*) to dry and moist environments (representing logged and unlogged forests) with and without predators. When no predator is present two-lined salamanders chose a moist environment. When a predator is present in the moist environment, the adult two-lined salamanders chose to remain in the less suitable dry environment, while juveniles display no clear choice. After logging, two-lined salamanders are faced with a decision between two adverse environments, with either decision likely resulting in a population decline. Determining amphibian responses to forest management practices is a key step to developing management plans for these forest-dependent species.

## Introduction

While there are many types of habitat loss and degradation (e.g., agriculture, land development), most studies have focused on the impacts of logging on wildlife populations (e.g., Gram et al. 2003; Constantine et al. 2004; Goldstein et al. 2005) and on ecosystem processes (e.g., Ash 1995; Swank et al. 2001; Wilkerson et al. 2006). For amphibians, much of the work has focused on pond-breeding amphibians or amphibians that do not require water for reproduction. Little information, however, exists on the effects of logging on amphibians that require streams for reproduction. In the Pacific Northwest, a few studies have begun to address this need (Grialou et al. 2000; Johnston & Frid 2002). Johnston and Frid (2002) found that Pacific giant salamanders (*Dicamptodon tenebrosus*) were found significantly closer to streams in clearcut forests versus unlogged forests. Additionally these salamanders spent more time in subterranean refuges, had smaller home ranges, and were more dependent on precipitation for movement in clearcuts than salamanders found at forested sites.

In the eastern part of the United States, the effects of logging have focused on a specific family of salamanders (Plethodontidae). Plethodontid salamanders make up an important ecological component of many forested ecosystems and often exceed the combined biomass of other terrestrial vertebrates throughout the Appalachian mountain region (Burton & Likens 1975; Hairston 1987; Petranka & Murray 2001). Numerous studies have documented the impacts of logging on woodland salamanders (*Plethodon*) (Petranka et al. 1993; Ash 1997; Hicks & Pearson 2003). However, all of these salamanders are completely terrestrial, have direct development, and do not require water for reproduction, which means they are not constrained to terrestrial areas near streams.

Yet, most members of the Plethodontidae require streams for reproduction and larval development, but the effects of logging on these salamanders remains an area in need of investigation.

In the southern Appalachian Mountains, stream salamanders spatially segregate themselves in the terrestrial habitat, most likely due to competition and predation (Hairston 1949; Organ 1961). In stream salamander assemblages in western North Carolina, Crawford and Semlitsch (2007) found four focal species that were spatially separated from one another. The majority of dusky salamanders (*Desmognathus quadramaculatus*, *D. monticola*, and *D. ocoee*) resided within 15 m of the stream's edge, whereas Blue Ridge two-lined salamanders (*Eurycea wilderae*) occurred primarily beyond 15-20 m (and up to 100 m) from the stream's edge. This is most likely due to predation and competition pressures exerted by the larger dusky salamanders on the two-lined salamanders. Both black-bellied salamanders (*D. quadramaculatus*) and seal salamanders (*D. monticola*) are large bodied and prey on juvenile and adult two-lined salamanders (Beachy 1993; Crawford personal observation). Thus, when forested areas around streams are logged, the brook salamanders are forced into an "ecological decision" between two adverse environments. Either they choose to remain in less suitable habitat (e.g., drier, no leaf litter), risking desiccation and potential death, or they choose to move closer to the stream and face higher risks of predation and greater rates of competition from dusky salamanders.

The purpose of my study was to determine the ecological response of two-lined (*E. wilderae*) salamanders to two high risk environments that occur as a result of logging in riparian forests near headwater streams. I performed a laboratory experiment to test

the behavioral decision of the Blue Ridge two-lined salamander (*E. wilderae*) to determine the effects of logging on stream salamander spatial dynamics. Specifically, the two-lined salamanders were forced to make a choice between dry habitat without a predator where the risk of desiccation was high versus moist habitat with a predator where the risk of being eaten was high.

## **Methods**

### Capture and Housing of Animals

I collected 90 two-lined salamanders (57 adults and 33 juveniles), six black-bellied salamanders, and six seal salamanders from the Highlands Ranger District of the Nantahala National Forest, North Carolina during July of 2005. All salamanders were captured by hand while searching riparian areas near headwater streams at night. After capture, all salamanders were housed in an environmental chamber at the Highlands Biological Field Station. The chamber had a 14 Light:10 Dark photoperiod, 65% relative humidity, and a constant temperature of 21 °C. Each seal salamander and black-bellied salamander was kept in an individual Gladware® container (15.5 x 15.5 x 5 cm) with a moist paper towel. Five two-lined salamanders were kept in each Gladware® container (15.5 x 15.5 x 5 cm) with a moist paper towel. No salamander was kept more than two weeks after its initial capture. After completion of the experiment, all salamanders were released at their site of capture.

## Experimental Design

I performed 3 experiments to determine what choice two-lined salamanders will make between two adverse environments. In the first experiment I presented the salamanders with a choice between dry soil and moist soil, with both sides lacking a predator. The soil moisture values in the chambers were similar to those found at a recent clearcut near a headwater stream where a 9 m buffer strip was retained (Crawford and Semlitsch unpubl. data; Table 1). As distance from the stream increased the soil moisture values decreased (Table 1). In the subsequent two experiments, salamanders were presented with a choice of dry soil without a predator and moist soil with a predator (seal salamanders in the second experiment and black-bellied salamanders in the third experiment).

In all experiments, the test chambers were rectangular Rubbermaid® containers (61 x 40.6 x 22.2 cm) that were divided in half width-wise by a piece of plastic. The plastic divider was held in place with silicone caulking, which also prevented the diffusion of water from the moist side of the container to the dry side of the container. Holes were cut in the lids of the containers and then window screening was placed over the openings. Commercial potting soil was put on both sides of the chamber and then water was added to the moist side of the chamber (a small spray bottle was used to apply eight ounces to the moist side). I then placed a small plastic bowl (15 cm diameter, 8 cm depth) with holes drilled through it on each end of the chamber, one as a control and the other containing a predator. The bowls prevented predators from moving and potentially preying on the two-lined salamanders. However, the bowls were clear and had holes so the two-lined salamanders could detect both visual and olfactory cues from the predator.

All experiments were performed during the night photoperiod of the environmental chamber because salamanders are nocturnally active. For each experiment, I used six test chambers and salamanders were randomly assigned to a chamber. To begin an experiment the salamander was placed in the center of the chamber with the body oriented perpendicular to the length of the chamber. Each chamber was inspected once every 10 min for 1 hr with a small flashlight so as not to disturb the salamanders and alter their behavior. If a salamander was on the center divider, the snout position was used to assign the choice (McGregor and Teska 1989). Once the experiment was completed, a soil sample from both the dry side and moist side was taken and dried in an oven for 12 hrs to calculate soil moisture. This was done to ensure that there was a significant moisture difference between the two sides. The rest of the soil was discarded and the test chamber was washed to eliminate any potential chemical cues for subsequent experiments. All two-lined salamanders were used only once during the course of this study and a total of 30 salamanders were used in each of the three experiments (N = 90 total). All experiments were completed between 25 July and 6 August of 2005.

### Data Analysis

For each of the three experiments, I used a 2-tailed binomial test to determine whether the two-lined salamanders chose the side of the chamber with moist soil or dry soil more than expected by chance. Six observations were made during the hour and I classified choice (moist or dry side of the chamber) based on where I recorded greater than 50% of the observations. No salamander in any of the three experiments spent an equal amount of observations on each side so classification was unambiguous. Both adults and juveniles

were analyzed together for an overall response and separately for an age-class response. To ensure that moisture levels on the two sides of the chamber were significantly different, I performed a t-test of independence.

## **Results**

In the first experiment testing the choice between the dry and moist side of the chamber with no predator present, two-lined salamanders (both adults and juveniles combined) chose the moist side of the chamber 93% of the time (28 of 30;  $P < 0.001$ ; Figure 1). Average soil moisture on the moist side of the chamber (23.75%) was significantly different from the dry side of the chamber (14.86%) ( $t = 6.98$ ,  $df = 58$ ,  $P < 0.001$ ). Adult two-lined salamanders chose the moist side of the chamber 88% of the time (15 of 17;  $P = 0.002$ ). Average soil moisture on the moist side of the chamber (23.92%) was significantly higher than moisture on the dry side (15.53%) ( $t = 5.11$ ,  $df = 32$ ,  $P < 0.001$ ). Juvenile two-lined salamanders chose the moist side of the chamber 100% of the time (13 of 13;  $P < 0.001$ ). Average soil moisture on the moist side of the chamber (23.53%) was significantly higher than moisture on the dry side (13.98%) ( $t = 4.65$ ,  $df = 24$ ,  $P < 0.001$ ).

In the second experiment, an adult seal salamander was used as a predator and placed under a clear plastic container on the moist side of the chamber. In this experiment the two-lined salamanders chose the dry side of the chamber 80% of the time (24 of 30;  $P = 0.002$ ; Figure 2). Average soil moisture on the moist side of the chamber (21.72%) was significantly different from moisture on the dry side of the chamber (11.39%) ( $t = 17.47$ ,  $df = 58$ ,  $P < 0.001$ ). Adult two-lined salamanders chose the dry side

of the chamber 86% of the time (18 of 21;  $P = 0.001$ ). Average soil moisture on the moist side of the chamber (21.59%) was significantly higher than moisture on the dry side (11.22%) ( $t = 14.53$ ,  $df = 40$ ,  $P < 0.001$ ). Juvenile two-lined salamanders chose the dry side of the chamber 67% of the time (6 of 9;  $P = 0.508$ ). Average soil moisture on the moist side of the chamber (22.02%) was significantly higher than moisture on the dry side (11.78%) ( $t = 9.31$ ,  $df = 16$ ,  $P < 0.001$ ).

In the third experiment, an adult black-bellied salamander was used as a predator and placed under a clear plastic container on the moist side of the chamber. In this experiment the two-lined salamanders chose the dry side of the chamber 73% of the time (22 of 30;  $P = 0.018$ ; Figure 3). Average soil moisture on the moist side of the chamber (23.69%) was significantly different from moisture on the dry side of the chamber (10.68%) ( $t = 20.75$ ,  $df = 58$ ,  $P < 0.001$ ). Adult two-lined salamanders chose the dry side of the chamber 95% of the time (18 of 19;  $P < 0.001$ ). Average soil moisture on the moist side of the chamber (23.88%) was significantly higher than moisture on the dry side (10.62%) ( $t = 15.81$ ,  $df = 36$ ,  $P < 0.001$ ). Juvenile two-lined salamanders chose the dry side of the chamber only 36% of the time (4 of 11;  $P = 0.549$ ). Average soil moisture on the moist side of the chamber (23.35%) was significantly higher than moisture on the dry side (10.77%) ( $t = 13.23$ ,  $df = 20$ ,  $P < 0.001$ ).

## **Discussion**

Two-lined salamanders are lungless animals that require cool, moist environments to carry on dermal respiration (Petranka 1998). Spotila (1972) found that some

plethodontids choose environments with the highest relative humidity to slow water loss to the environment. Additionally, he found that as plethodontid salamanders decreased in size the relative amount of water loss from dehydration increased. This is supported by the fact that 100% and 88% of the juveniles and adults, respectively, in the first experiment of my study chose the moist side of the test chamber.

In the southern Appalachian Mountains, clear-cutting of forests results in reduced litter dry mass (amount of leaf litter), leaf litter depth, and leaf litter moisture (Ash 1995). One outcome of clear-cutting is the disappearance of salamanders within two years after logging (Ash 1988; Ash 1997; Crawford & Semlitsch unpub. data). Considering the physiological requirements of two-lined salamanders, one would expect salamanders in clear cut plots to move to moister and more suitable habitat closer to the stream. However, Crawford and Semlitsch (2007) found that two-lined salamanders were found greater than 15 m away from headwater streams surrounded by intact riparian forest, and this was most likely due to predation by larger stream salamanders who reside within 15 m of the stream's edge.

As expected, in the first experiment (choice between moist and dry environments with no predator present), the two-lined salamanders (adults and juveniles) strongly preferred the moist side of the test chamber. In the subsequent two experiments (choice between the moist side with a predator and the dry side without a predator), the adult two-lined salamanders chose the dry side and avoided both species of predators. In order to avoid predation, two-lined salamanders chose to remain in less suitable habitat with a high risk of desiccation that they would normally avoid.

This avoidance of predators has serious implications concerning the trade-off in movement of adult two-lined salamanders between two unsuitable habitats. Most stream amphibians are highly philopatric (Welsh and Ollivier 1998) and many amphibians have relatively low vagilities (Cushman 2006). If the adult two-lined salamanders were to try to leave the cut areas for the nearest suitable habitat they would have to use the stream as a corridor. Considering the results of my study, it is unlikely the adult two-lined salamanders will move closer to the stream and face higher predation risks from the larger salamander species, but rather would chose to risk desiccation. The decision by the adults to risk desiccation over predation suggests their relatively large body size may ameliorate the desiccation risk but does not prevent predation.

The juvenile two-lined salamanders made different choices than the adult salamanders. In the second experiment using a seal salamander (*D. monticola*) as a predator, three juveniles chose the moist side and six juveniles chose the dry side. In the third experiment using a black-bellied salamander (*D. quadramaculatus*), seven juveniles chose the moist side and four juveniles chose the dry side. Thus, in the face of two risky environments it appears that juveniles viewed desiccation equally as risky as predation. Regardless of which side the juveniles chose in any of the three experiments, they always curled up in a water conservation position. This curling decreases surface area to volume ratio and most likely slows the rate of evaporative water loss. In the second and third experiments using predators, the juveniles who did choose the moist side were always in the water conservation position and were located as far from the predator as possible (i.e. they were just across the divider in the corner). The smaller body size (and increased

surface area:volume ratio) forces the juveniles to risk the greater threat of predation suggesting that the risk of desiccation is higher.

While choosing to remain in a logged area could result in desiccation and potential death, it is possible that the adult two-lined salamanders could tolerate the unsuitable conditions related to desiccation. Soil moisture can remain unchanged after logging (Ash 1988; Seastedt and Crossley 1981). This might allow adults to persist in the cut areas for a period of time. It is more likely that the juveniles would not be able to tolerate the harsh desiccating environment and would move closer to the stream, risking a chance of predation.

The response of the two-lined salamanders to the ecological decision faced as a result of logging is likely not a species-specific response. In the southern Appalachian mountains, the Ocoee salamander (*Desmognathus ocoee*) is found an average of 8.2 m from headwater stream edges (Crawford and Semlitsch 2007). Although Ocoee salamanders do not range as far from the stream as two-lined salamanders, they face the same predation and desiccation issues due to their small body size. Both seal salamanders (*D. monticola*) and black-bellied salamanders (*D. quadramaculatus*) are known predators of Ocoee salamanders (Petranka 1998; Crawford pers. obs.).

Plethodontid salamanders are a key component of forested ecosystems because they serve as a primary predator on invertebrates and serve as prey for other larger vertebrates (Pough et al. 1987). When a riparian forest is logged near a stream, two-lined salamanders will likely have to make a choice between desiccation and predation. Either scenario would likely lead to increased mortality and a local decline in population numbers (e.g., Hairston 1987; Jaeger et al. 1998). Similar species to the two-lined

salamander that are of special concern such as the Junaluska salamander (*Eurycea junaluska*) may also be especially vulnerable. Further, population declines of stream salamanders can be detrimental to the ecosystem because they provide a functional link between aquatic and terrestrial habitats. Determining behavioral responses and trade-offs of species to forest management practices is a critical first step in larger scale issues such as developing management plans to conserve amphibians in fragmented and degraded habitats and reversing declines of sensitive species.

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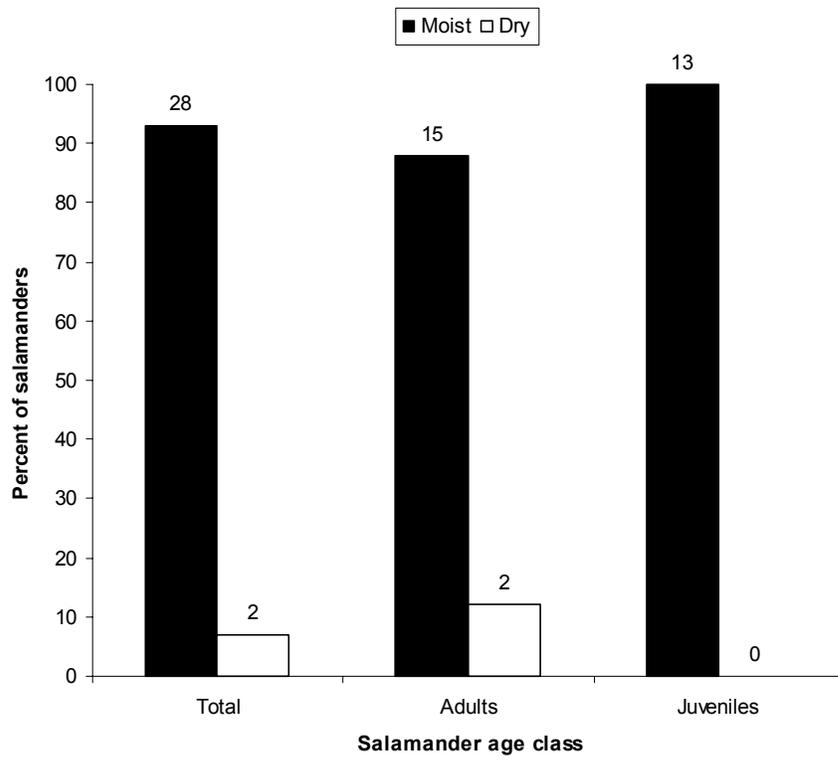
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**Table 1. Soil moisture as a function of distance from the stream at a recent clearcut site with a 9 m buffer retained in the Nantahala National Forest, North Carolina<sup>a</sup>.**

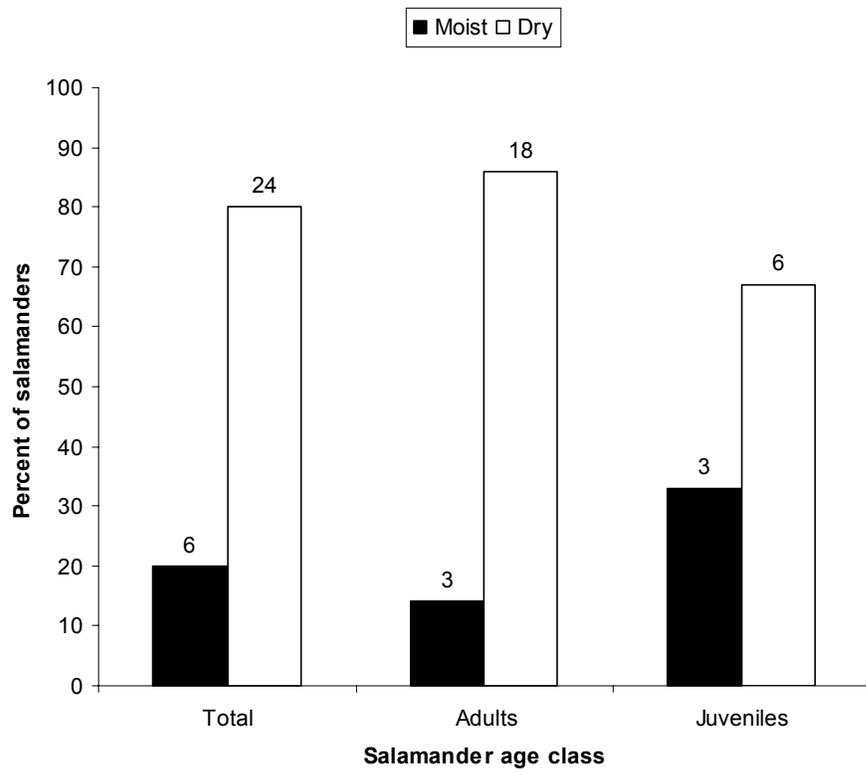
<i>Distance from stream (m)</i>	<i>June</i>	<i>July</i>	<i>August</i>	<i>Average</i>
1	27	31	30	29.3
3	28	24	28	26.7
7	21	23	22	22.0
10	18	23	17	19.3
15	17	17	18	17.3
25	11	14	13	12.7
50	13	12	8	11.0
100	8	13	9	10.0

<sup>a</sup>*Soil moisture values are recorded in percentages.*

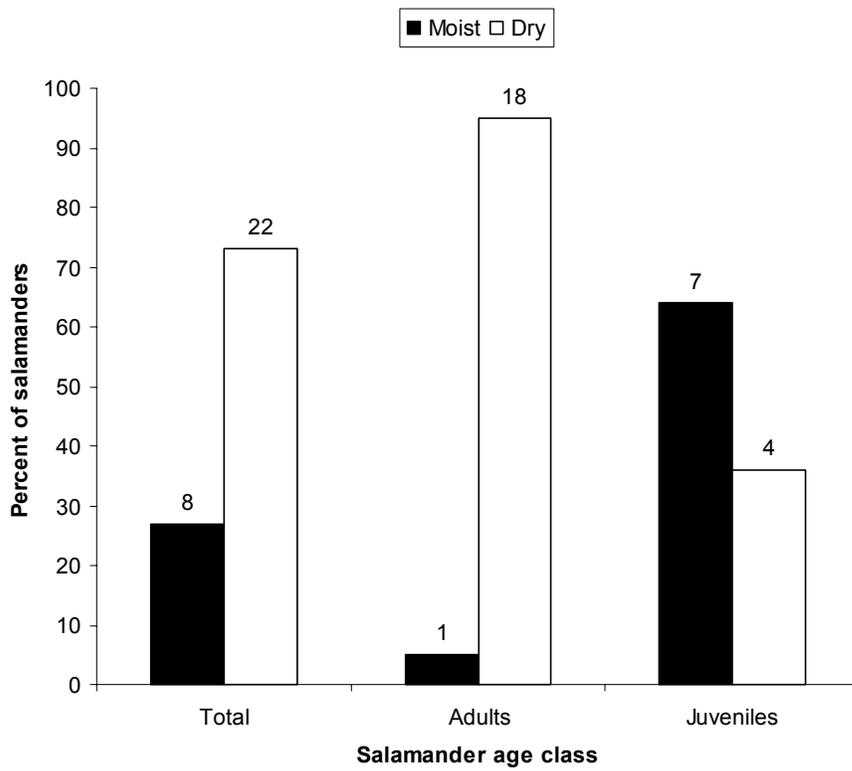
**Figure 1.** The percent of two-lined salamanders that selected moist versus dry environments with no predator present in the moist environment. Total represents all two-lined salamanders tested. Adults and juveniles were also analyzed separately to determine an age class response. Number of individuals is listed above the bar.



**Figure 2.** The percent of two-lined salamanders that selected moist versus dry environments with a predator (seal salamander) present in the moist environment. Total represents all two-lined salamanders tested. Adults and juveniles were also analyzed separately to determine an age class response. Number of individuals is listed above the bar.



**Figure 3.** The percent of two-lined salamanders that selected moist versus dry environments with a predator (black-bellied salamander) present in the moist environment. Total represents all two-lined salamanders tested. Adults and juveniles were also analyzed separately to determine an age class response. Number of individuals is listed above the bar.



## Chapter 6

### EFFECTS OF EVEN-AGED TIMBER HARVEST AND RIPARIAN ZONE WIDTH ON STREAM SALAMANDERS IN THE SOUTHERN APPALACHIAN MOUNTAINS

John A. Crawford and Raymond D. Semlitsch

#### **Abstract**

With increased attention on amphibian declines in the past decade, many agree the primary factor responsible for this decline is habitat fragmentation and degradation. A number of studies have begun to address the impacts of forest management practices on amphibian populations. In the eastern United States many of the studies have focused on fully terrestrial plethodontid salamanders, while information on stream-breeding plethodontids remains relatively lacking. Using two different survey methods (area-constrained daytime searches and nighttime visual encounter searches), we estimated mean core terrestrial habitat and abundance for stream-breeding salamanders before and after logging at sites with different riparian buffer widths in southern Appalachian streams from May to August 2004-2006. We found that overall stream salamander abundance and core terrestrial habitat use was significantly reduced after logging occurred at sites where no buffer or only a 9 m buffer was retained. The decreased abundance and use of core terrestrial habitat in stream salamanders was accompanied by a significant decrease in leaf litter depth, soil moisture, and canopy cover along with a

significant increase in soil temperature. The Blue Ridge two-lined salamander (*Eurycea wilderae*) was the most affected salamander in the assemblage. We estimate that a 9 m riparian buffer is inadequate to protect stream salamander assemblages. To protect stream amphibians, alternative silvicultural practices, such as uneven-aged timber harvest (e.g., selective harvesting) should be considered as well as application of larger riparian buffer zone widths.

## **Introduction**

With the increasing concern over amphibian declines in the past two decades, many factors have been implicated in the declines such as disease, introduction of exotic species, chemical pollution, and global climate change (Lips 1998; Wake 1998; Carey et al. 1999). These multiple causes have likely contributed to the fact that amphibians are far more threatened than either birds or mammals (Stuart et al. 2004). As of 2006, the World Conservation Union (IUCN) found that of 40,177 species assessed using IUCN Red List criteria, 16,199 are now listed as threatened with extinction (IUCN 2006). They found that one out of every eight bird species, one out of every four mammal species, and one out of every three species of amphibians was at risk of extinction (IUCN 2006). Currently, habitat loss and degradation are generally accepted as the major factor responsible for most amphibian declines (Semlitsch 2000; Cushman 2006). Amphibians are especially sensitive to loss and degradation of habitat due to their unique life history requirements (i.e. most amphibians require both aquatic and terrestrial resources to complete their life cycle).

Habitat loss and degradation can result from a number of processes (e.g., land development, agriculture). Within the past decade a number of studies have examined the impacts of timber harvesting on wildlife populations (e.g., Gram et al. 2003; Constantine et al. 2004; Goldstein et al. 2005) and on ecosystem processes (e.g., Ash 1995; Swank et al. 2001; Wilkerson et al. 2006) in the United States. Little information, however, exists on the effects of logging on amphibians that require streams for reproduction (Grialou et al. 2000; Johnston & Frid 2002). Johnston and Frid (2002) found that Pacific giant salamanders (*Dicamptodon tenebrosus*) were found significantly closer to streams in clearcut forests versus unlogged forests. Additionally these salamanders spent more time in subterranean refuges, had smaller home ranges, and were more dependent on precipitation for movement in clearcuts than salamanders found at forested sites.

To mitigate habitat loss and degradation in stream ecosystems (in addition to providing wildlife corridors and protecting essential habitat required for completing the life cycles of riparian species), riparian buffer strips adjacent to streams have been used in managed forests for more than two decades (Vesely & McComb 2002). Buffer strips protect water quality from activities such as agriculture and silviculture, which cause siltation and increased water temperatures (Lowrance et al. 1984; Jones et al. 1999; Vesely & McComb 2002). However, riparian buffer strips are not only critical to the protection of aquatic resources; they can play a role in the conservation of biodiversity. A number of studies have documented the importance of terrestrial habitat adjacent to streams and wetlands for semiaquatic species, including amphibians (e.g., deMaynadier & Hunter 1995; Semlitsch 1998; Vesely & McComb 2002). One study has documented

the effectiveness of riparian buffer strips by showing that 20 m strips contained approximately 80% of detectable torrent salamanders (*Rhyacotriton* spp.), Pacific giant salamanders (*Dicamptodon tenebrosus*), and Dunn's salamanders (*Plethodon dunni*) along the first- through third-order streams (Vesely and McComb 2002).

In the eastern part of the United States, the effects of logging have focused on one genus (*Plethodon*) of salamanders in the family Plethodontidae. Plethodontid salamanders make up an important ecological component of many forested ecosystems and often exceed the combined biomass of other terrestrial vertebrates throughout the Appalachian mountain region (Burton & Likens 1975; Hairston 1987; Petranka & Murray 2001). Previous studies examining the impacts of timber management activities on salamanders typically investigated how salamander populations responded to various cutting practices (Duguay and Wood 2002). Normally, both the species composition and abundance of salamanders declined after timber harvesting (Pough et al. 1987; Petranka et al. 1993; Harpole and Haas 1999). deMaynadier and Hunter (1995) reviewed 18 studies of amphibian responses to clearcutting and found that amphibian abundance was 3.5 times higher in unharvested stands than in recent clearcuts. However, most of these studies focus on strictly terrestrial amphibians (e.g., *Plethodon*) that have direct development and do not require water for reproduction, which means they are not constrained to terrestrial areas near streams. Yet, most members of the Plethodontidae require streams for reproduction and larval development. Thus, effects of logging and effectiveness of riparian buffers for these salamanders is critical to understanding the impacts of timber management and conserving salamander biodiversity in the eastern United States.

The purpose of our research is to determine the effectiveness of riparian buffers for stream salamanders in recently clearcut forests in the southern Appalachian Mountains. Specifically, we compared the amount of terrestrial habitat use and salamander abundance in experimental forests that were recently clearcut and left with variable riparian buffer widths. Based on previous studies of plethodontids, we hypothesized that the amount of terrestrial habitat use and salamander abundance would decrease significantly as the width of the riparian buffer decreased.

## **Methods**

### Study Area

To determine the effect of riparian buffer width on the amount of terrestrial habitat use and salamander abundance, we sampled the riparian forest adjacent to four sites in the Wine Spring Creek study area, Wayah Ranger District, Nantahala National Forest, North Carolina. The Wine Spring Creek study area is especially important, because a significant amount of baseline data on water quality, aquatic habitat and biota, and vegetation are available from previous studies conducted as a part of the Wine Spring Creek Ecosystem Management Demonstration Project (pers. comm. J. Vose). Within the study area, four small watersheds (< 10 acres each) were selected and assigned to one of four treatments: 0 m riparian width with upland harvest, 9 m riparian width with upland harvest, and 30 m riparian width with upland harvest, and a control (no harvest). The 9 m and 30 m riparian zone widths bracket current guidelines for southern Appalachian watersheds. Logging occurred in the winter of 2005 and spring of 2006. To insure

maximum capture success and detection of rare species (Hyde & Simons 2001), we used two different sampling methods. Sites were sampled six times each (three day transects, three night transects) from May-August for three years (2 pre-cut years and 1 post-cut year; 2004-2006).

### Daytime Sampling

During daytime transects, we sampled a paired transect that was separated by  $\geq 1$  m (to increase sample sizes of salamanders; data for each plot were combined) and extended perpendicular from the stream bank into the adjacent forest at each site. Monitoring stations were established at 1, 3, 7, 10, 15, 25, 50, and 100 m from the stream bank, based on the home range sizes and potential distances traveled by the target species of stream-breeding salamanders (Crawford & Semlitsch 2007). At each stream, we conducted the three daytime transects by using area-constrained searches of each plot (2 x 2.25 m<sup>2</sup> or 4.5 m<sup>2</sup> per station) by sifting through leaf litter and coarse woody debris at each monitoring station for an average of 10 minutes. At each plot, data was collected on four environmental variables: 1) Leaf litter depth – measured three times in each plot (6 times per station) using a hand ruler for an average leaf litter depth value; 2) Soil temperature – measured three times in each plot (6 times per station) using an infrared Raytek® MT4 temperature gun for an average temperature value; 3) Soil moisture – measured three times in each plot (6 times per station) using an Aquaterr® M300 soil moisture meter for an average soil moisture value; and 4) Canopy cover – measured one time in each plot (2 times per station) using a spherical crown densiometer for an average canopy cover value.

We identified all salamanders to species, weighed and measured for snout-vent length and total length, determined sex, and recorded the distance from the stream. We released all salamanders at the site of capture. We determined age class (adult or juvenile) by comparing measured snout-vent lengths of each individual to published size classes for each species (Petranka 1998).

### Nighttime Sampling

We used a visual encounter search (VES) during the three night transects to capture surface-active salamanders at each site. Two researchers walked a straight line that was perpendicular from the stream edge (defined as the edge of the streambed) out to 100 m and recorded distance from the stream edge for each salamander encountered. While walking the perpendicular transect, each researcher searched 2.5 m to the right and left of the transect line. We processed salamanders in the nighttime samples the same as detailed above for the daytime samples.

### Data Analysis

We used the mean distance from the stream edge to estimate core terrestrial habitat use by salamanders for each sample. Mean core terrestrial habitat use and salamander abundance was calculated for the assemblage of four species and each individual species (except for black-bellied salamanders where sample sizes were too small to justify a separate analysis). We used a t-test of independence to test the effectiveness of remaining riparian buffers after logging on mean core terrestrial habitat use, stream salamander abundance, and environmental variables. Tests with  $p < 0.10$  were considered

statistically significant. Due to the lack of spatial replication, data from all four sites in both 2004 and 2005 pre-cut years were pooled and tested against data collected in the post-cut year 2006. Pooling data from the two pre-cut years was justified because there was no significant difference in mean core terrestrial habitat use or abundance between 2004 and 2005.

## **Results**

### Control Site

#### *Daytime Sampling*

Between 2004-2006, 58 total stream salamanders of four different species (seal salamanders – *Desmognathus monticola*, Ocoee salamanders – *D. ocoee*, black-bellied salamanders – *D. quadramaculatus*, and Blue Ridge two-lined salamanders – *Eurycea wilderae*) were captured during daytime sampling. We captured 14 salamanders in 2004, 24 salamanders in 2005, and 20 salamanders in 2006. Stream salamander abundance was 6.4 salamanders/transect before the cuts occurred (2004-2005) and 6.7 salamanders/transect after the cuts occurred (2006; Table 1). Stream salamander abundance was not significantly different after cuts occurred ( $t = 0.541$ ,  $df = 7$ ,  $p = 0.605$ ). There was no significant difference in abundance after cuts occurred for seal salamanders, Ocoee salamanders, or two-lined salamanders ( $t = 0.646$ ,  $df = 7$ ,  $p = 0.539$ ;  $t = 1.126$ ,  $df = 7$ ,  $p = 0.297$ ;  $t = 0.776$ ,  $df = 7$ ,  $p = 0.463$ , respectively; Table 1).

Stream salamanders were found an average of 5.1 m from the stream before the cuts occurred and 4.8 m after the cuts occurred (Table 2). Average distance from the

stream was not significantly different after the cuts occurred ( $t = 0.827$ ;  $df = 7$ ;  $p = 0.435$ ). There was no significant difference in average distance from the stream for seal salamanders, Ocoee salamanders, or two-lined salamanders ( $t = 0.749$ ,  $df = 7$ ,  $p = 0.478$ ;  $t = 0.525$ ,  $df = 7$ ,  $p = 0.616$ ;  $t = 0.492$ ,  $df = 7$ ,  $p = 0.638$ , respectively; Table 2).

Average leaf litter depth, average soil temperature, average soil moisture, and average canopy cover were not significantly different after the cuts occurred ( $t = 0.952$ ,  $df = 7$ ,  $p = 0.373$ ;  $t = 0.475$ ,  $df = 7$ ,  $p = 0.649$ ;  $t = 0.337$ ,  $df = 7$ ,  $p = 0.746$ ;  $t = 0.062$ ,  $df = 7$ ,  $p = 0.952$ , respectively; Table 3).

### *Nighttime Sampling*

Between 2004-2006, 95 total stream salamanders of four different species were captured during nighttime sampling. We captured 25 salamanders in 2004, 40 salamanders in 2005, and 30 salamanders in 2006. Stream salamander abundance was 10.8 salamanders/transect before the cuts occurred and 10.0 salamanders/transect after the cuts occurred (Table 4). Stream salamander abundance was not significantly different after cuts occurred ( $t = 0.283$ ,  $df = 7$ ,  $p = 0.785$ ). There was no significant difference in abundance after cuts occurred for seal salamanders, Ocoee salamanders, or two-lined salamanders ( $t = 0.122$ ,  $df = 7$ ,  $p = 0.906$ ;  $t = 0.505$ ,  $df = 7$ ,  $p = 0.629$ ;  $t = 0.329$ ,  $df = 7$ ,  $p = 0.752$ , respectively; Table 4).

Stream salamanders were found an average of 27.0 m from the stream before the cuts occurred and 23.7 m after the cuts occurred (Table 5). Average distance from the stream was not significantly different after the cuts occurred ( $t = 0.915$ ;  $df = 7$ ;  $p = 0.391$ ). There was no significant difference in average distance from the stream for seal

salamanders, Ocoee salamanders, or two-lined salamanders ( $t = 0.457$ ,  $df = 7$ ,  $p = 0.661$ ;  $t = 0.200$ ,  $df = 7$ ,  $p = 0.847$ ;  $t = 0.744$ ,  $df = 7$ ,  $p = 0.481$ , respectively; Table 5).

### 30 m Site

#### *Daytime Sampling*

Between 2004-2005, 43 total stream salamanders of four different species were captured during daytime sampling. We captured 26 salamanders in 2004 and 17 salamanders in 2005. Stream salamander abundance was 7.2 salamanders/transect before the cuts occurred (Table 1). Stream salamanders were found an average of 6.6 m from the stream before the cuts occurred (Table 2). During the field season of 2006, logging was not completed at this site until late September, which prevented the collection of post-cut data.

#### *Nighttime Sampling*

Between 2004-2005, 66 total stream salamanders of four different species were captured during nighttime sampling. We captured 42 salamanders in 2004 and 24 salamanders in 2005. Stream salamander abundance was 11.0 salamanders/transect before the cuts occurred (Table 4). Stream salamanders were found an average of 25.9 m from the stream before the cuts occurred (Table 5).

## 9 m Site

### *Daytime Sampling*

Between 2004-2006, 36 total stream salamanders of four different species were captured during daytime sampling. We captured 14 salamanders in 2004, 17 salamanders in 2005, and 5 salamanders in 2006. Stream salamander abundance was 5.2 salamanders/transect before the cuts occurred and 1.7 salamanders/transect after the cuts occurred (Table 1). Stream salamander abundance was significantly reduced after cuts occurred ( $t = 2.006$ ,  $df = 7$ ,  $p = 0.085$ ). There was a significant decrease in abundance of seal salamanders, but there was no significant difference in abundance after cuts occurred for Ocoee salamanders, or two-lined salamanders ( $t = 1.970$ ,  $df = 7$ ,  $p = 0.090$ ;  $t = 1.576$ ,  $df = 7$ ,  $p = 0.159$ ;  $t = 1.114$ ,  $df = 7$ ,  $p = 0.302$ , respectively; Table 1).

Stream salamanders were found an average of 6.5 m from the stream before the cuts occurred and 1.8 m after the cuts occurred (Table 2). Average distance from the stream was significantly different after the cuts occurred ( $t = 2.158$ ;  $df = 7$ ;  $p = 0.068$ ). There was no significant difference in average distance from the stream for seal salamanders, Ocoee salamanders, however there was a significant decrease for two-lined salamanders ( $t = 1.719$ ,  $df = 7$ ,  $p = 0.129$ ;  $t = 0.616$ ,  $df = 7$ ,  $p = 0.558$ ;  $t = 1.986$ ,  $df = 7$ ,  $p = 0.087$ , respectively; Table 2).

Average leaf litter depth, average soil temperature, average soil moisture, and average canopy cover were all significantly different after the cuts occurred ( $t = 10.714$ ,  $df = 7$ ,  $p < 0.001$ ;  $t = 12.560$ ,  $df = 7$ ,  $p < 0.001$ ;  $t = 13.719$ ,  $df = 7$ ,  $p < 0.001$ ;  $t = 66.679$ ,  $df = 7$ ,  $p < 0.001$ , respectively; Table 3).

### *Nighttime Sampling*

Between 2004-2006, 84 total stream salamanders of four different species were captured during nighttime sampling. We captured 42 salamanders in 2004, 32 salamanders in 2005, and 10 salamanders in 2006. Stream salamander abundance was 12.4 salamanders/transect before the cuts occurred and 3.3 salamanders/transect after the cuts occurred. Stream salamander abundance was significantly reduced after cuts occurred ( $t = 2.363$ ,  $df = 7$ ,  $p = 0.050$ ). There was no significant difference in abundance after cuts occurred for seal salamanders or Ocoee salamanders ( $t = 0.122$ ,  $df = 7$ ,  $p = 0.906$ ;  $t = 1.029$ ,  $df = 7$ ,  $p = 0.338$ , respectively; Table 4). Two-lined salamanders were significantly reduced in abundance after the cuts occurred ( $t = 3.685$ ,  $df = 7$ ,  $p = 0.008$ ; Table 4).

Stream salamanders were found an average of 26.7 m from the stream before the cuts occurred and 2.4 m after the cuts occurred (Table 5). Average distance from the stream was significantly reduced after the cuts occurred ( $t = 7.390$ ;  $df = 7$ ;  $p < 0.001$ ). There was no significant difference in average distance from the stream for seal salamanders or Ocoee salamanders ( $t = 1.170$ ,  $df = 7$ ,  $p = 0.280$ ;  $t = 1.561$ ,  $df = 7$ ,  $p = 0.162$ , respectively; Table 5). Two-lined salamanders were found significantly closer to the stream after the cuts occurred ( $t = 7.322$ ,  $df = 7$ ,  $p < 0.001$ ; Table 5).

### 0 m Site

#### *Daytime Sampling*

Between 2004-2006, 23 total stream salamanders of four different species were captured during daytime sampling. We captured 10 salamanders in 2004, 13 salamanders in 2005, and 0 salamanders in 2006. Stream salamander abundance was 3.8 salamanders/transect

before the cuts occurred and 0.0 salamanders/transect after the cuts occurred (Table 1). Stream salamander abundance was significantly reduced after cuts occurred ( $t = 2.872$ ,  $df = 7$ ,  $p = 0.024$ ). There was no significant difference in abundance after cuts occurred for two-lined salamanders ( $t = 1.519$ ,  $df = 7$ ,  $p = 0.173$ ; Table 1). Seal salamanders and Ocoee salamanders were significantly reduced in abundance after the cuts occurred ( $t = 1.970$ ,  $df = 7$ ,  $p = 0.090$ ;  $t = 2.877$ ,  $df = 7$ ,  $p = 0.024$ , respectively; Table 1).

Stream salamanders were found an average of 8.5 m from the stream before the cuts occurred and 0.0 m after the cuts occurred (Table 2). Average distance from the stream was significantly different after the cuts occurred ( $t = 2.957$ ;  $df = 7$ ;  $p = 0.021$ ). There was no significant difference in average distance from the stream for seal salamanders or Ocoee salamanders ( $t = 1.719$ ,  $df = 7$ ,  $p = 0.129$ ;  $t = 0.889$ ,  $df = 7$ ,  $p = 0.403$ , respectively; Table 2). Two-lined salamanders were found significantly closer to the stream after the cuts occurred ( $t = 2.434$ ,  $df = 7$ ,  $p = 0.045$ ; Table 2).

Average leaf litter depth, average soil temperature, average soil moisture, and average canopy cover were all significantly different after the cuts occurred ( $t = 10.714$ ,  $df = 7$ ,  $p < 0.001$ ;  $t = 12.560$ ,  $df = 7$ ,  $p < 0.001$ ;  $t = 13.719$ ,  $df = 7$ ,  $p < 0.001$ ;  $t = 66.679$ ,  $df = 7$ ,  $p < 0.001$ , respectively; Table 3).

### *Nighttime Sampling*

Between 2004-2006, 63 total stream salamanders of four different species were captured during nighttime sampling. We captured 19 salamanders in 2004, 38 salamanders in 2005, and 6 salamanders in 2006. Stream salamander abundance was 9.5 salamanders/transect before the cuts occurred and 2.0 salamanders/transect after the cuts

occurred. Stream salamander abundance was significantly reduced after cuts occurred ( $t = 2.766$ ,  $df = 7$ ,  $p = 0.028$ ). There was no significant difference in abundance after cuts occurred for seal salamanders or Ocoee salamanders ( $t = 0.305$ ,  $df = 7$ ,  $p = 0.769$ ;  $t = 1.777$ ,  $df = 7$ ,  $p = 0.119$ , respectively; Table 4). Two-lined salamanders were significantly reduced in abundance after the cuts occurred ( $t = 3.685$ ,  $df = 7$ ,  $p = 0.008$ ; Table 4).

Stream salamanders were found an average of 27.1 m from the stream before the cuts occurred and 1.3 m after the cuts occurred (Table 5). Average distance from the stream was significantly reduced after the cuts occurred ( $t = 7.716$ ;  $df = 7$ ;  $p < 0.001$ ). There was no significant difference in average distance from the stream for seal salamanders ( $t = 1.184$ ,  $df = 7$ ,  $p = 0.275$ ; Table 5). Ocoee salamanders and two-lined salamanders were found significantly closer to the stream after the cuts occurred ( $t = 2.081$ ,  $df = 7$ ,  $p = 0.076$ ;  $t = 7.322$ ,  $df = 7$ ,  $p < 0.001$ , respectively; Table 5).

## **Discussion**

We found that overall abundances of stream salamanders sampled both during the day and night censuses were significantly reduced from pre-cut levels at the 0 m site and the 9 m site. While there were significant reductions in the number of seal salamanders at both of the logged sites and significantly fewer Ocoee salamanders at the 0 m site, the two-lined salamanders experienced the greatest reduction in abundance at both logged sites relative to the control and pre-cut data. A number of factors could account for this difference among species. Two-lined salamanders are relatively small and slender salamanders (< 110 mm total length). Their body size leads to an increased surface

area:volume ratio and higher risk of water loss than the other larger species of salamanders (Spotila 1972). These salamanders forage for invertebrates in the leaf litter and when this leaf litter becomes thinner, drier, or both it is unlikely they will have the moisture necessary to remain hydrated and to carry on dermal respiration. Additionally, with a reduction in leaf litter, adequate populations of invertebrate prey may not be present (Ash 1995). With a decrease in leaf litter and available space, competition with other species will likely increase for invertebrate prey.

A number of studies have documented the importance of factors such as canopy cover, leaf litter availability, and soil parameters in the abundance and distribution of plethodontid salamanders (Spotila 1972; Ash 1997; Harper & Guynn Jr. 1999; Hicks & Pearson 2003; McKenny et al. 2006). Salamanders in the family Plethodontidae, which is a lungless family of salamanders (Petranka 1998), are even more dependent on moist habitats for water balance and dermal respiration than other families of amphibians. We found that leaf litter depth, soil moisture, and canopy cover were all significantly lower while soil temperature was significantly higher at both the 0 m and 9 m sites. Reduction in leaf litter depth and leaf litter moisture was also reported by Ash (1995) and Buckner and Shure (1985) following clearcutting in southern Appalachian forests. Timber harvest can also degrade habitat for salamanders because the elimination of canopy cover can result in increased soil temperature and decreased surface soil moisture (Petranka et al. 1994; Ash 1997; Herbeck & Larsen 1999; Crawford & Semlitsch this study).

The amount of core terrestrial habitat used by the stream salamanders in our study sites before logging (2004-2005) was similar to values found by Crawford and Semlitsch (2007) in mature forests within the nearby Highlands Ranger District. We found that

core terrestrial habitat was significantly reduced for the entire assemblage at both of the logged sites. It was reduced for two-lined salamanders during daytime and nighttime sampling at the 0 m site and the 9 m site. Ocoee salamanders had a reduction in core terrestrial habitat use at the 0 m site, but not at the 9 m site. The reduction in amount of core terrestrial habitat used by the stream salamanders is likely related to the reduced habitat quality (loss of leaf litter depth and moisture) resulting from the timber harvest. The decrease in the amount of suitable core terrestrial habitat results in the decreased abundance of stream salamanders in the stands that underwent logging. The decrease in core terrestrial habitat use by two-lined salamanders is especially important in terms of salamander abundance. Crawford and Semlitsch (2007) showed that the majority of dusky salamanders (*Desmognathus* spp.) are found within 15 m of the stream's edge, whereas two-lined salamanders occurred beyond 20 m of the stream's edge. This was likely due to competition and predation from the larger dusky salamanders. At the logged sites, the two-lined salamanders are being forced closer to the stream which likely results in greater competition and predation pressures from the larger dusky salamanders and a subsequent decline in population number.

While the seal salamanders and Ocoee salamanders seemed to be only marginally affected by the logging, the two-lined salamanders were greatly affected. The two-lined salamanders seem to be the most sensitive species to the disturbance and when a riparian forest is logged near a stream, two-lined salamanders will likely have to make a choice between desiccation if they remained in the logged areas and predation if they moved near the stream (Crawford *In Review*). Either scenario would likely lead to increased mortality and a decline in population numbers (e.g., Hairston 1987; Jaeger et al. 1998).

Similar species to the two-lined salamander that are of special concern such as the Junaluska salamander (*Eurycea junaluska*) may also be especially vulnerable.

Currently, there are three competing hypotheses as to what happens to plethodontid salamanders after timber harvest occurs: 1) the mortality hypothesis suggests that salamanders die as a result of the logging; 2) the dispersal hypothesis suggests that salamanders immediately leave the logged areas; and 3) the refuge hypothesis suggests that salamanders retreat into underground burrows to try and survive. While our data show that stream salamanders significantly decline after timber harvest and the retention of a 9 m buffer does not seem to mitigate this effect, the mechanisms of the decline remain unknown. If the more terrestrial stream salamanders (e.g., Ocoee salamanders and two-lined salamanders) were to disperse from the logged areas, the most likely path of dispersal would be through the stream. Peterman and Semlitsch (unpubl. data) found that the number of Ocoee salamanders was higher in streams where logging occurred compared to un-logged controls (Table 6). However, these smaller salamanders will most likely encounter a greater number of predators as they move closer to the stream. Crawford and Semlitsch (2007) found that the larger species of dusky (*Desmognathus*) salamanders occur near the stream. The smaller stream salamanders are likely forced into a decision of dispersal (and risking predation) and taking refuge in the suboptimal terrestrial habitat. Crawford (*In Review*) found that adult two-lined salamanders chose to remain in a drier environment when a predator was present in the moister environment. The juvenile two-lined salamanders chose to move to the moist environment and most likely risk predation.

Plethodontid salamanders are a key component of forested ecosystems because they serve as a primary predator on invertebrates and serve as prey for other larger vertebrates (Pough et al. 1987). Most stream-breeding salamanders are highly philopatric, long-lived, and usually exist in relatively stable populations (Hairston 1987). These life history traits make them reliable indicators of potential biotic diversity in stream and riparian ecosystems, and their relative abundance and core habitat use can be a critical indicator of stream and riparian ecosystem health (Welsh Jr. & Ollivier 1998; Crawford & Semlitsch 2007). Although we have begun to gain some insight into the mechanisms of decline of stream salamanders after timber harvesting, more research is needed in this area. Determining both the direct and indirect causes of salamander declines will help to evaluate alternative forest management practices such as selective harvesting (e.g., thinning, group selection). We hope this research stimulates future work on the impacts of even-aged timber harvesting and effectiveness of riparian buffers in maintaining terrestrial wildlife populations in riparian habitats.

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**Table 1.** Summary of stream salamander abundances from daytime transects at the four experimental logging sites in the Wayah Ranger District, Nantahala National Forest (2004-2006).<sup>a</sup>

<i>Site/Year</i>	<i>Species</i>			
	<i>Assemblage<sup>b</sup></i>	<i>D. monticola</i>	<i>D. ocoee</i>	<i>E. wilderae</i>
Control 2004	4.7	0.3	3.3	1.0
2005	8.0	2.3	3.3	2.3
2006	6.7	1.0	4.0	1.7
30 m 2004	8.7	2.3	3.7	2.0
2005	5.7	2.0	3.0	0.7
2006	N/A	N/A	N/A	N/A
9 m 2004	4.7	1.3	1.7	1.3
2005	5.7	1.0	4.0	0.7
2006	1.7	0.0	1.3	0.3
0 m 2004	3.3	1.7	1.3	0.3
2005	4.3	1.0	2.7	0.7
2006	0.0	0.0	0.0	0.0

<sup>a</sup>*Abundance is number of salamanders captured per transect.*

<sup>b</sup>*Assemblage denotes all salamanders (Desmognathus monticola, Desmognathus ocoee, Desmognathus quadramaculatus, and Eurycea wilderae).*

**Table 2.** Summary of daytime occurrence distances<sup>a</sup> (m) from stream edge of the salamander assemblage at the four experimental logging sites in the Wayah Ranger District, Nantahala National Forest (2004-2006).

<i>Site/Year</i>	<i>Species</i>			
	<i>Assemblage<sup>b</sup></i>	<i>D. monticola</i>	<i>D. ocoee</i>	<i>E. wilderae</i>
Control 2004	5.6, 9.9 n = 14	1.0, N/A n = 1	2.2, 3.6 n = 10	18.3, 32.7 n = 3
2005	4.5, 7.1 n = 24	3.6, 8.3 n = 7	1.8, 3.2 n = 10	9.4, 17.0 n = 7
2006	4.8, 7.8 n = 20	2.3, 5.2 n = 3	2.0, 3.2 n = 12	13.0, 23.5 n = 5
30 m 2004	5.9, 9.0 n = 26	3.3, 8.1 n = 7	2.7, 4.5 n = 11	15.8, 26.6 n = 6
2005	7.4, 10.7 n = 17	3.0, 5.3 n = 6	7.6, 11.0 n = 9	20.0, 83.5 n = 2
2006	N/A	N/A	N/A	N/A
9 m 2004	5.5, 9.5 n = 14	3.5, 7.5 n = 4	1.4, 2.5 n = 5	13.3, 28.0 n = 4
2005	7.5, 13.8 n = 17	3.7, 11.3 n = 3	5.3, 9.2 n = 12	26.5, 325.1 n = 2
2006	1.8, 3.2 n = 5	0.0, 0.0 n = 0	1.5, 3.1 n = 4	3.0, N/A n = 1

0 m 2004	11.3, 18.8	8.0, 20.6	16.5, 34.6	7.0, N/A
	n = 10	n = 5	n = 4	n = 1
2005	5.6, 10.1	7.0, 19.9	1.5, 2.3	20.0, 83.5
	n = 13	n = 3	n = 8	n = 2
2006	0.0, 0.0	0.0, 0.0	0.0, 0.0	0.0, 0.0
	n = 0	n = 0	n = 0	n = 0

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<sup>a</sup>*Distance encompassing 50% and 95% of the population, respectively.*

<sup>b</sup>*Assemblage denotes all salamanders (Desmognathus monticola, Desmognathus ocoee, Desmognathus quadramaculatus, and Eurycea wilderae).*

**Table 3.** Environmental variables for riparian areas at the four experimental logging sites in the Wayah Ranger District, Nantahala National Forest (2004-2006).

<i>Site/Year</i>	<i>Environmental variables</i>			
	<i>Leaf litter (mm)</i>	<i>Soil temperature (°C)</i>	<i>Soil moisture (%)</i>	<i>Canopy (%)</i>
Control 2004	32.7	20.5	38.2	93.1
Control 2005	30.7	20.5	34.2	91.4
Control 2006	29.2	20.0	35.4	91.4
30 m 2004	32.4	19.9	35.5	92.5
30 m 2005	35.0	19.9	38.2	90.8
30 m 2006	N/A	N/A	N/A	N/A
9 m 2004	29.9	18.3	36.5	91.5
9 m 2005	29.4	19.1	36.1	90.1
9 m 2006	17.2	24.8	18.6	19.6
0 m 2004	30.2	19.3	36.0	90.7
0 m 2005	29.4	19.4	33.4	90.5
0 m 2006	8.7	29.7	11.5	19.1

**Table 4.** Summary of stream salamander abundances from nighttime transects at the four experimental logging sites in the Wayah Ranger District, Nantahala National Forest (2004-2006).<sup>a</sup>

<i>Site/Year</i>	<i>Species</i>			
	<i>Assemblage<sup>b</sup></i>	<i>D. monticola</i>	<i>D. ocoee</i>	<i>E. wilderae</i>
Control 2004	8.3	1.0	1.0	6.3
2005	13.3	3.0	2.7	7.7
2006	10.0	1.3	2.0	6.0
30 m 2004	14.0	1.0	4.7	8.3
2005	8.0	0.7	3.7	3.7
2006	N/A	N/A	N/A	N/A
9 m 2004	14.0	4.7	3.0	5.7
2005	10.7	0.3	2.3	8.0
2006	3.3	1.7	1.3	0.0
0 m 2004	6.3	0.3	1.0	5.0
2005	12.7	1.0	3.0	8.0
2006	2.0	1.0	0.3	0.0

<sup>a</sup>*Abundance is number of salamanders captured per transect.*

<sup>b</sup>*Assemblage denotes all salamanders (Desmognathus monticola, Desmognathus ocoee, Desmognathus quadramaculatus, and Eurycea wilderae).*

**Table 5.** Summary of nighttime occurrence distances<sup>a</sup> (m) from stream edge of the salamander assemblage at the four experimental logging sites in the Wayah Ranger District, Nantahala National Forest (2004-2006).

<i>Site/Year</i>	<i>Species</i>			
	<i>Assemblage<sup>b</sup></i>	<i>D. monticola</i>	<i>D. ocoee</i>	<i>E. wilderae</i>
Control 2004	30.8, 38.2 n = 25	11.7, 29.1 n = 3	13.7, 17.5 n = 3	36.5, 44.6 n = 19
2005	23.3, 30.4 n = 40	7.7, 10.8 n = 9	7.6, 14.0 n = 8	34.8, 44.7 n = 23
2006	23.7, 30.3 n = 30	5.0, 7.6 n = 4	8.3, 12.0 n = 6	35.1, 41.8 n = 18
30 m 2004	27.1, 35.2 n = 42	8.7, 14.9 n = 3	5.6, 8.2 n = 14	41.4, 51.7 n = 25
2005	24.6, 33.8 n = 24	8.0, 84.2 n = 2	8.9, 12.4 n = 11	42.3, 56.1 n = 11
2006	N/A	N/A	N/A	N/A
9 m 2004	23.4, 31.5 n = 42	4.8, 6.7 n = 14	8.2, 11.9 n = 9	49.2, 60.9 n = 17
2005	30.0, 36.8 n = 32	15.0, N/A n = 1	6.1, 10.2 n = 7	37.6, 44.0 n = 24
2006	2.4, 3.5 n = 10	1.4, 2.1 n = 5	3.8, 6.1 n = 4	0.0, 0.0 n = 0

0 m 2004	29.5, 38.1	1.0, N/A	14.0, 20.6	34.5, 43.6
	n = 19	n = 1	n = 3	n = 15
2005	24.7, 32.3	1.7, 4.5	7.9, 12.2	35.9, 45.2
	n = 38	n = 3	n = 9	n = 24
2006	1.3, 1.9	1.3, 2.8	2.0, N/A	0.0, 0.0
	n = 6	n = 3	n = 1	n = 0

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<sup>a</sup>*Distance encompassing 50% and 95% of the population, respectively.*

<sup>b</sup>*Assemblage denotes all salamanders (Desmognathus monticola, Desmognathus ocoee, Desmognathus quadramaculatus, and Eurycea wilderae).*

**Table 6.** In stream capture data of Ocoee salamanders from logged and unlogged sites in the Wayah Ranger District, Nantahala National Forest (2006)\*.

<i>Site</i>	<i>Life History Stage</i>			<i>Total</i>
	<i>Adults</i>	<i>Juveniles</i>	<i>Metamorphs</i>	
Control	12	9	18	39
9 meter buffer	9	11	26	46
0 meter buffer	53	30	21	104

*\*Data courtesy of W.E. Peterman and R.D. Semlitsch*

## Chapter 7

### SUMMARY AND CONSERVATION IMPLICATIONS

John A. Crawford

#### **Core Terrestrial Habitat Use (Chapter 2)**

1. Using two different survey methods (area-constrained daytime searches and nighttime visual encounter searches), we estimated core terrestrial habitat use and buffer widths for stream-breeding salamanders in southern Appalachian streams from May to August 2004. Additionally, we also devised a direct test of whether day versus night sampling yields the best estimate of core terrestrial habitat use for these salamanders.
2. We defined core terrestrial habitat as the spatial delineation of 95% of the population that encompasses terrestrial foraging, breeding, and overwintering habitats, which was determined by the 95% confidence interval. The day transects yielded a core terrestrial habitat estimate of 10.7 m, whereas the adjusted night transects yielded a significantly different core terrestrial habitat estimate of 15.8 m. The overall night transects yielded a core habitat estimate of 27.0 m that was more than double the estimate based on day transects. The two different genera we encountered have drastically different core terrestrial habitat requirements. Although the difference in core terrestrial habitat usage between adults and juveniles within each genus was minimal, the difference between

dusky (*Desmognathus*) salamanders and brook (*Eurycea*) salamanders was large (8.5 m for dusky vs. 42.6 m for brook).

3. Current U.S. Forest Service (USFS) guidelines for southern Appalachian streams require an ~ 9-m (30 feet) buffer for headwater through second-order streams and an ~ 30-m (100 feet) buffer for streams third-order and above. Our results show that USFS buffer regulations would not be adequate to protect brook (*Eurycea*) salamanders in smaller streams and would provide dusky (*Desmognathus*) salamanders with little protection from edge effects. We would argue that our core terrestrial habitat estimate of 27.0 m for a stream salamander assemblage is conservative. Our core terrestrial habitat value was calculated with all four stream species found in the assemblage; however the estimate failed to fully protect one of the dominant species (*E. wilderae*). If the overall goal of core terrestrial habitats and buffer zones is to protect both diversity and abundance of an assemblage, we suggest calculating individual estimates for each species and using the greatest core terrestrial habitat estimate. This ensures protection of each species within the assemblage. Based on our results for *E. wilderae* alone, we recommend a core terrestrial habitat of 42.6 m and an overall buffer width of 92.6 m in southern Appalachian streams. Additionally, we found that daytime searches lead to inadequate estimation of the amount of habitat salamanders require. This distinction is important because most plethodontid monitoring techniques employ only daytime searches and likely underestimate core terrestrial habitat use.

### **Microhabitat Use and Abundance (Chapter 3)**

1. To determine microhabitat use and stream salamander abundance, we sampled riparian forests using an area-constrained daytime search from May to August of 2004. At each stream, we conducted three collections by using area-constrained searches of each plot (2.25 m<sup>2</sup>) by sifting through leaf litter and coarse woody debris at each plot distance for an average of 10 minutes. Plot distances were established at 1, 3, 7, 10, 15, 25, 50, and 100 m from the stream bank, based on the home range sizes and potential distances traveled by the target species of stream-breeding salamanders.
2. We found that leaf litter depth, soil moisture, and canopy cover were all higher and soil temperature was lower in plots where stream salamanders were found. A regression analysis using the information theoretic approach (AIC) revealed that the model that included distance from stream, leaf litter depth, soil moisture, and soil temperature had the strongest support for predicting stream salamander abundance at the landscape level ( $\omega_i = 0.99$ ). For each of the three individual species (seal salamanders, Ocoee salamanders, and two-lined salamanders) both leaf litter depth and soil moisture were much higher in plots where these species were found. Additionally, we found that in the 149 plots that we captured stream salamanders, only 11 of these plots had salamanders of two or more species.
3. These results provide further evidence that leaf litter depth, soil moisture, and soil temperature are critical to overall stream salamander abundance and microhabitat use. Salamanders in the family Plethodontidae, which is a lungless family of salamanders, are even more dependent on moist habitats for dermal respiration

than other families of amphibians. These salamanders forage for invertebrates in the leaf litter and when this leaf litter becomes thinner, the soil becomes drier, or both, it is unlikely they will have the moisture necessary to carry on dermal respiration. Additionally, individuals cannot forage during dry periods because of the high rates of water loss. Habitat degradation and alteration most likely cause a reduction in the amount of microhabitat available and force smaller salamanders into a choice of suboptimal microhabitat or increasing predation risk in more suitable microhabitats. Either of these choices likely results in decreased abundances and salamanders being found closer to streams. To mitigate the effects of practices such as even-aged timber harvesting, alternatives such as uneven-aged harvesting techniques (i.e., selective harvesting) should be considered. We also recommend implementing more stringent buffer zone criteria around streams of all types.

#### **Post-Disturbance Effects of Even-Aged Timber Harvest (Chapter 4)**

1. We sampled stream salamanders in three different stand-age categories to determine the effects of post-disturbance timber harvest and estimate recovery time of stream salamander populations in southern Appalachian streams. Specifically, we compared core terrestrial habitat use and stream salamander abundance in riparian areas found in three stand age-classes using two different survey methods (area-constrained daytime searches and nighttime visual encounter searches) from May to August 2005. Further, we examined the

difference in four environmental variables (leaf litter depth, soil moisture, soil temperature, and canopy cover) among the different stand-age classes.

2. Our data showed that leaf litter depth, soil moisture, and canopy cover were all lower in stands  $\leq 40$  years of age when compared to stands between the ages of 41-80 years, and stands  $\geq 81$  years of age. Additionally, our regression analyses revealed that the leaf litter depth and distance from the stream were the two most important predictors of stream salamander abundance. We found that overall abundances of stream salamanders sampled both during the day and night were reduced in stands  $\leq 40$  years of age when compared to the older stand age classes. While there were no significant reductions in the number of seal salamanders (*Desmognathus monticola*) or Ocoee salamanders (*D. ocoee*), there were significantly fewer Blue Ridge two-lined salamanders (*E. wilderae*) in the youngest stands ( $\leq 40$  years old) in both day and night transects. Last, we found that core terrestrial habitat use was significantly reduced in stands  $\leq 40$  years of age for the entire assemblage. It was reduced for two-lined salamanders during daytime sampling and for all three species (seal salamanders, Ocoee salamanders, and two-lined salamanders) during nighttime sampling.
3. While the seal salamanders and Ocoee salamanders seemed to be only marginally affected by stand age, the two-lined salamanders were greatly affected. The two-lined salamanders seem to be the most sensitive species to the disturbance and take the longest period of time to recover in the assemblage. A number of factors could account for this difference among species. Two-lined salamanders are relatively small and slender salamanders ( $< 110$  mm total length). Their body size

leads to an increased surface area:volume ratio and higher risk of water loss than the other larger species of salamanders. These salamanders forage for invertebrates in the leaf litter and when this leaf litter becomes thinner, drier, or both it is unlikely they will have the moisture necessary to carry on dermal respiration. Additionally, with a reduction in leaf litter, adequate populations of invertebrate prey may not be present. With a decrease in leaf litter and available space, competition with other species will likely increase for invertebrate prey. We estimate that it would take at least 40 years for the entire assemblage to recover to pre-disturbance levels. This estimate falls within the range of values that have been found for other plethodontid salamanders in the southern Appalachian Mountains.

### **Desiccation and Predation Risk in Two-Lined Salamanders (Chapter 5)**

1. After logging, Blue Ridge two-lined salamanders (*Eurycea wilderae*) are faced with a decision between two adverse environments, with either decision likely resulting in a population decline. Using a laboratory experiment, I investigated the behavioral choice of two-lined salamanders to dry and moist environments (representing logged and unlogged forests) with and without predators. I performed 3 experiments to determine what choice two-lined salamanders will make between two adverse environments. In the first experiment I presented the salamanders with a choice between dry soil and moist soil, with both sides lacking a predator. In the subsequent two experiments, salamanders were presented with a choice of dry soil without a predator and moist soil with a predator (seal

salamanders, *Desmognathus monticola*, in the second experiment and black-bellied salamanders, *D. quadramaculatus*, in the third experiment).

2. As expected, in the first experiment (choice between moist and dry environments with no predator present), the two-lined salamanders (adults and juveniles) strongly preferred the moist side of the test chamber. In the subsequent two experiments (choice between the moist side with a predator and the dry side without a predator), the adult two-lined salamanders chose the dry side and avoided both species of predators. In order to avoid predation, two-lined salamanders chose to remain in less suitable habitat with a high risk of desiccation that they would normally avoid.
3. These data show that the avoidance of predators has serious implications concerning the trade-off in movement of adult two-lined salamanders between two unsuitable habitats. Most stream amphibians are highly philopatric and many amphibians have relatively low vagilities. If the adult two-lined salamanders were to try to leave the cut areas for the nearest suitable habitat they would have to use the stream as a corridor. Considering the results of my study, it is unlikely the adult two-lined salamanders will move closer to the stream and face higher predation risks from the larger salamander species, but rather would chose to risk desiccation. The decision by the adults to risk desiccation over predation suggests their relatively large body size may ameliorate the desiccation risk but does not prevent predation. The juvenile two-lined salamanders made different choices than the adult salamanders. In the second experiment using a seal salamander (*D. monticola*) as a predator, three juveniles chose the moist side and six juveniles

chose the dry side. In the third experiment using a black-bellied salamander (*D. quadramaculatus*), seven juveniles chose the moist side and four juveniles chose the dry side. Thus, in the face of two risky environments it appears that juveniles viewed desiccation equally as risky as predation. When a riparian forest is logged near a stream, two-lined salamanders will likely have to make a choice between desiccation and predation. Either scenario would likely lead to increased mortality and a decline in population numbers. Similar species to the two-lined salamander that are of special concern such as the Junaluska salamander (*Eurycea junaluska*) may also be especially vulnerable.

#### **Even-Aged Timber Harvest and Buffer Width Effects (Chapter 6)**

1. Using two different survey methods (area-constrained daytime searches and nighttime visual encounter searches), we estimated mean core terrestrial habitat use and abundance for stream-breeding salamanders before and after logging at sites with different riparian buffer widths in southern Appalachian streams from May to August 2004-2006. Within the study area, four small watersheds (< 10 acres each) were selected and assigned to one of four treatments: 0 m riparian width with upland harvest, 9 m riparian width with upland harvest, and 30 m riparian width with upland harvest, and a control (no harvest). The 9 m and 30 m riparian zone widths bracket current guidelines for southern Appalachian watersheds. Logging occurred in the winter of 2005/spring of 2006. During the field season of 2006, logging was not completed at the 30 m site until late September, which prevented the collection of post-cut data.

2. We found that leaf litter depth, soil moisture, and canopy cover were all significantly lower while soil temperature was significantly higher at both the 0 m and 9 m sites. Additionally, overall abundances of stream salamanders sampled both during the day and night were significantly reduced at the 0 m site and abundance was significantly reduced during the night at the 9 m site. While there were no significant reductions in the number of seal salamanders at either of the logged sites, there were significantly fewer Blue Ridge two-lined salamanders at both of the logged sites, and significantly fewer Ocoee salamanders at the 0 m site. Last, our data showed that core terrestrial habitat use was significantly reduced for the entire assemblage at both of the logged sites. It was reduced for two-lined salamanders during daytime sampling at the 0 m site, but not at the 9 m site (although it approached biological significance). Two-lined salamanders also had a significant reduction in core terrestrial habitat use at both logged sites during nighttime sampling. Neither seal salamanders nor Ocoee salamanders had a reduction in core terrestrial habitat use.
3. Our results show that the seal salamanders and Ocoee salamanders seemed to be only marginally affected by the logging, but the two-lined salamanders were greatly affected. The two-lined salamanders seem to be the most sensitive species to the disturbance. When a riparian forest is logged near a stream, two-lined salamanders will likely have to make a choice between desiccation and predation. Either scenario would likely lead to increased mortality and a decline in population numbers. The decrease in the amount of suitable core terrestrial habitat results in the decreased abundance of stream salamanders in the stands that

underwent logging. The decrease in core terrestrial habitat use by two-lined salamanders is especially important in terms of salamander abundance. Previous work (Chapter 2) showed that the majority of dusky salamanders (*Desmognathus* spp.) are found within 15 m of the stream's edge, whereas two-lined salamanders occurred beyond 20 m of the stream's edge. This was likely due to competition and predation from the larger dusky salamanders. At the logged sites, the two-lined salamanders are being forced closer to the stream which likely results in greater competition and predation pressures from the larger dusky salamanders and a subsequent decline in population number.

## VITA

John Alexander Crawford was born on 20 February 1976 in Danville, Illinois and grew up in the small town of Fithian, Illinois. He graduated from Oakwood Township High School in May 1994 and went on to earn a B.S. from the Department of Biology at the University of Illinois (Urbana-Champaign) in May 1998. John then enrolled at Illinois State University (Bloomington-Normal) where he earned a M.S. from the Division of Biological Sciences in December 2000 with an emphasis in Ecology in Evolution. His thesis work was entitled “Investigation of Aggressive and Satellite Behavior in the Cricket Frog *Acris crepitans*”. John then earned his Ph.D. from the Division of Biological Sciences at the University of Missouri (Columbia) in July 2007 with an emphasis in Ecology and Evolution. John will begin a post-doctoral appointment at Indiana University in August 2007 where he will study the effects of timber harvest on amphibian populations in the boreal forests of Alberta, Canada.