SALAMANDER DISTRIBUTIONS AROUND A HEADWATER STREAM IN THE HUBBARD BROOK EXPERIMENTAL FOREST, NEW HAMPSHIRE

NEITH LITTLE[1] AND SYLVIA POWELL[2]
[1]*College of the Atlantic, Bar Harbor, ME 04609 USA*
[2]*Earlham College, Richmond, IN 47374 USA*

MENTOR SCIENTIST: GENE E. LIKENS
Institute of Ecosystem Studies, Millbrook, NY 12545 USA

Abstract. Streamside and terrestrial salamanders are important components of forest and riparian ecosystems in New Hampshire. Their status as amphibians, which are currently suffering global declines, and as potential indicator species, necessitates study of their natural history and habitat needs, particularly to inform design of legislation supporting buffer zones to be left adjacent to streams. We conducted an exploratory baseline study of salamander distributions around a headwater stream in the Hubbard Brook Experimental Forest, New Hampshire. We encountered two salamander species in our transects, which extended 50 m away from the stream: *Eurycea bislineata,* which were encountered mostly within 20 m of the stream, and *Plethodon cinereus*, which showed no significant distribution pattern.

INTRODUCTION

Recently, much research has been done exploring global declines and disappearances of amphibian populations (e.g. Alford & Richards 1999, Stuart et al. 2004, Blaustein et al. 1994). In a site in the northeastern U.S.A., salamander biomass has been found to exceed that of birds and equal that of small mammals (Burton and Likens 1975b). *Plethodon cinereus*, the species that made up 93.5% of that biomass, is also thought to be in decline at that site (Likens, G.E., personal communication), and their high biomass suggests that other species might be affected by changes in these salamanders' populations. Thus, it may prove vital to forest conservation and management to understand salamander habitat requirements and interactions. Additionally, Welshe and Droege (2001) have proposed that because amphibians may be particularly sensitive to environmental degradation, their populations could be monitored to quantify the effects of habitat change on ecosystems. A baseline understanding of healthy salamander populations is also needed for this purpose.

Knowledge about salamander populations and distributions is also needed to determine effective conservation requirements, such as the size of buffer zones to be left around streams when forests are logged. Several previous studies have addressed this need. Wilson and Dorcas (2003) tested the response of *Desmognathus fuscus* and *Eurycea cirrgera* to different levels of disturbance around streams and in watersheds in North Carolina. They found that the remedial effects of buffer zones were far outweighed by the detrimental effects of watershed-wide disturbance. Crawford and Semlitsch (2007) estimated buffer widths that would be effective in conserving stream-breeding amphibians in the southern Appalachian mountains. They found 95% of stream amphibians encountered within 27 m of the stream and recommended an overall buffer width of 92 m Perkins and Hunter (2006) examined the effects of logging practices and buffer zones of varied widths on both stream-breeding and terrestrial amphibians in inland Maine. Their results suggested that buffers of 11 to 35 m left undisturbed might be of benefit to some amphibian species, including *P. cinereus.*

Our study examined salamander distributions around a headwater stream in a mixed-hardwood forest that had not been logged since ca. 1920. We focused on two salamander species, *Eurycea bislineata,* the northern two-lined salamander, and *Plethodon cinereus,* the northern red-backed salamander. We explored their streamside habitat use in the Hubbard Brook Experimental Forest (HBEF), in the White Mountains of New Hampshire. The HBEF has been the site of decades of environmental research, including several influential salamander studies. Burton and Likens (1975b) conducted their measurements of salamander biomass at HBEF and (1975a) calculated energy flow and nutrient cycling through salamanders in the HBEF ecosystem. Burton (1976) went on to examine salamander gut contents in order to determine the feeding habits of all five species of salamanders found in HBEF. A more recent study at HBEF (Lowe 2003) measured in-stream dispersal of *Gyrinophilus porphyriticus*. We measured species evenness and relative abundance of *E. bislineata* and *P. cinereus* across the gradient (Heyer *et al.* 1994) of distance from a headwater stream.

MATERIALS AND METHODS

We conducted the study in the Hubbard Brook Experimental Forest, NH, between 23 July and 3 August, 2007. Geology, climate, vegetation, and nutrient cycling of this area have been described in detail in many previous papers (e.g. Bormann et al. 1969, 1970; Eaton et al. 1973; Likens et al. 1967, 1970; Likens and Buso 2006; Gosz et al. 1972, 1973; Siccama et al. 1970; Whittaker et al. 1974). We chose a study site in a mixed hardwood forest along the east bank of a stream on the north-facing side of the valley, named West Zigzag Brook (Likens and Buso 2006).

Because plethodontid salamanders are lungless, they must keep their skin moist in order to continue respiration. This necessitates sheltering in humid microhabitats under cover objects such as rotting logs or loose bark (Feder 1983). Thus, because we were studying species evenness and relative abundance across a gradient (proximity to the stream), and because salamanders tend to be found under identifiable cover objects, we chose to use a combination of strip transect and patch sampling methodologies (Heyer et al. 1994): we sampled patches (natural woody cover objects, such as logs or loose bark) within strip transects near West Zigzag Brook that encompassed varying distances from the stream.

However, because the curve of the stream bank made it impractical to lay transects out by eye and still maintain as little error as possible in measurements of distance from stream, we first created a map of the ca. 100 m of stream bank contained within our study site. We laid out lengths of surveyor's tape in the stream bed, recorded the bearings of those lengths, took range and bearing measurements perpendicular from those lengths to the stream bank (defined as the point where soil and vegetation began), plotted each point on the bank in MS Excel, and calculated the best fit line of that curve and the bearing of the best fit line, 239.5º. We thus chose a bearing of 329.5º (perpendicular to the best fit line of the stream bank) along which to lay out our transects.

We marked the stream-bank end of a transect every 10 m along the best fit line bearing. Because we chose to make each strip transect 50 m long and 6 m wide this left a buffer of ca. 4 m between each transect. Because we were searching under cover objects, where salamanders shelter partly to maintain skin moisture (Feder 1983), we chose to survey transects only on days when precipitation was negligible (lasted for less than 3 minutes). This procedure necessitated getting searches done while weather was suitable. Thus after searching one transect we laid out the transect to be searched the next day: we laid out 50 m of surveyor's tape from the flagged stream-bank endpoint along the 329.5º bearing. We attempted to follow the contour of the terrain with the surveyor's tape. Every 10 m we flagged the outer edge of the strip transect, 3 m out on either side from the centerline.

We assigned each transect a number, then randomized the order in which they were to be searched by using the list randomizer program on the website <www.random.org>. Because we worked together to complete each transect survey in as short a time period as possible, we attempted to minimize searcher bias by searching every suitable cover object patch (woody objects greater than 2.5 cm in diameter but small enough to be lifted by two people). We also divided each transect into five 10-m-long segments (0-10 m from stream, 10-20 m from stream, etc.). We used a random number table to randomize the order in which segments within a transect were searched. These segment divisions were used later in data analysis.

During each transect survey we first searched under every object in a segment, then measured the surface area of the object in contact with the substrate. We assigned each object that we searched a unique id number for later reference.

When a salamander was captured we weighed it in a tared plastic bag with a Pesola spring-scale and recorded species, snout-vent and tail lengths, decay class and id number of object found under, time found, and segment found in (10-20 m, 30-40 m, etc.). We then released salamanders where they had been found and marked their location with a flag so as to avoid inadvertently stepping on them during the rest of the transect survey. Escapes were recorded as location encountered and estimated species.

Before and after transect surveys we used a Kestrel ® weather meter to record air temperature, humidity, and wind-speed at the endpoints and midpoints of the transect. At the end of the season we spent a day collecting soil samples from each transect (three per 10. m segment, along the center of the strip transect). We scraped surface leaf litter away by hand to reduce soil compression, took samples with a soil corer and placed them in air-tight Whirl-Pak plastic bags that had been numbered and pre-weighed. We then calculated wet and dry weights to measure percent moisture content of the samples: samples were dried at 40° C in a drying oven until they crumbled easily and felt dry to the touch. They were then weighed on a digital scale and the weight of the drying containers were subtracted out.

We ran analyses using SYSTAT 8.0. Data were not normally distributed, so non-parametric tests were used.

RESULTS

In six 50-by-6 m transect surveys we searched 1437 natural woody cover objects, with a total cover area of 70.7 m^2. We encountered three species of salamanders: *Eurycea bislineata*, *Plethodon cinereus*, and *Notophthalmus viridescens*. The latter species was excluded from analyses because only one individual was encountered. We encountered 7 *E. bislineata* and 1 *P. cinereus* on top of the leaf litter, not associated with any woody cover object. These salamanders were excluded from analyses because the purpose of the study was to explore woody cover object use. We encountered 5 *E. bislineata* and 22 *P. cinereus* inside of (rather than underneath) rotting woody cover objects. These salamanders were also excluded from analyses because, while we were reasonably sure we counted every salamander *underneath* the cover objects we searched, we have no way to know how many salamanders *within* cover objects we overlooked. With these salamanders removed, our transect surveys collected data on 21 *E. bislineata* and 56 *P. cinereus*.

We had quantified distance from the stream by dividing transects into 10 m segments (0-10 m from the stream, 10-20 m, etc.). The 40-50 meter segment of Transect 1 was searched at a different time than the rest of the transects, during heavy precipitation, and was thus excluded from analyses.

Cover object area searched appeared to be distributed fairly evenly among our transect segments. Thus for analyses we looked at number of salamanders encountered per transect segment, rather than number of salamanders encountered per m^2 cover object area searched, because area searched had no statistically significant variation and dividing varied results by a relatively constant number might cause a type 1 error (Figure 1).

Of the 21 *E. bislineata* encountered under woody cover objects, 15 were found within ten meters of the stream bank and 2 in the 10-20 m segments of the transects. No *E. bislineata* were encountered under cover objects in the 20-30 and 30-40 m segments of the transects. Four *E. bislineata* were encountered under woody cover objects in the 40-50 m segments of the transects.

The *P. cinereus* encountered appear to have been distributed more evenly along the transects (Figure 4).

A Spearman correlation found a significant negative relationship between numbers of *E. bislineata* encountered and distance away from the stream (N=29, Spearman Test Statistic = -0.511. $p < 0.01$). There was no significant correlation between numbers of *P. cinereus* encountered and distance from stream (N=29, Spearman Test Statistic = 0.339, $p > 0.05$) (Figure 2).

Soil moisture content ((wet weight – dry weight)/dry weight) ranged from 16% to 303%. Median soil moisture content increases significantly with distance from stream (N = 87, Spearman Test Statistic = 0.282, p = 0.01). Also, number of *E. bislineata* or *P. cinereus* encountered in a segment increases with soil moisture content in that segment (*E. bislineata* and soil moisture content: N = 87, Spearman Test Statistic = 0.229, p = 0.01; *P. cinereus* and soil moisture content: N = 87, Spearman Test Statistic = 0.213, p = 0.05) (Figure 3).

DISCUSSION

The goal of our study was to answer the following question, which could be relevant to both buffer zone practices and baseline understandings of salamanders as indicator species and amphibians potentially requiring conservation: Do the relative abundances of each species and/or the overall species composition of salamanders encountered relate to distance from the stream?

Most of our *E. bislineata* results support the accepted understanding of that species' natural history: that two-lined salamanders live in and forage from streams (Petranka 1998). However, the four *E. bislineata* encountered in the 40-50 m segments of transects 4 and 6 differ from this pattern. This discrepancy might be related to the small rain run-off track, possibly an intermittent stream, no wider than 0.3 m, near the end of the transects. This soil moisture might have sustained the *E. bislineata* while distant from the stream. The number of both *E. bislineata* and *P. cinereus* encountered increased significantly with increased percent soil moisture content.

Our *P. cinereus* results suggest that their distribution under woody cover objects is unrelated to stream proximity. This finding suggests that when *P. cinereus* distributions under cover objects near a stream *did* vary, some factor other than stream proximity would need to be investigated. It is possible that if our study had encompassed more salamanders or during different seasons a pattern in *P. cinereus* distribution would have been found, but as the *E. bislineata* data set was even smaller and a pattern was found in that species' distribution, the lack of a pattern in *P. cinereus* encounters seems noteworthy. These results suggest that proximity to streams may not be a significant factor in the suitability of *P. cinereus* habitat. However, because this study was small-scale and exploratory, further study is needed to examine this possibility more thoroughly.

Salamanders encountered did increase significantly with soil moisture content. This fits with the conventional understanding of plethodontid salamander habitat needs, since their lack of lungs necessitates maintaining moist skin in order to respirate. The thinner vegetative canopy along the stream-bank may be a factor in the increase in soil moisture content with increasing distance from the stream.

These results suggest that buffer zones around streams would probably be more valuable to *E. bislineata*, which appear to congregate near the stream, than to *P. cinereus*, which do not appear to be as affected by stream proximity.

ACKNOWLEDGEMENTS

Our study was funded by the National Science Foundation through the Institute of Ecosystem Studies' (IES) Research Experiences for Undergraduates program. D.C. Buso, N. Cleavitt, W. Lowe, the U.S.D.A. Forest Service, and our IES mentors G.E. Likens and K. Judd provided advice and loaned equipment. D. Adams and A. Thrasher assisted with preliminary studies and helped lay out transects.

This material is based upon work supported by the National Science Foundation under Grant No. DBI 0552871.

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

LITERATURE CITED

Alford, R.A. and Richards, S.J. (1999) Global amphibian declines: a problem in applied ecology. *Annual Review of Ecology and Systematics* 30: 133-165.

Blaustein, A.R., D.B. Wake, and W.P. Sousa. (1994) Amphibian declines: judging stability, persistence, and susceptibility of populations to local and global extinctions. *Conservation Biology* 8(1): 60-71.

Bormann, F.H., G.E. Likens, and J.S. Eaton. 1969. Biotic regulations of particulate and solution losses from a forest ecosystem. *BioScience* 19(7):600-610.

Bormann, F.H., T.G. Siccama, G.E. Likens, and R.H. Whittaker. 1970. The Hubbard Brook Ecosystem Study: Composition and Dynamics of the Tree Stratum. *Ecological Monographs* 40(4):373-388.

Burton, T.M. (1976) An analysis of the feeding ecology of the salamanders (Amphibia, Urodela) of the Hubbard Brook Experimental Forest, New Hampshire. *Journal of Herpetology* 10(3): 187-204.

Burton, T.M. and Likens, G.E. (1975) Energy flow and nutrient cycling in salamander populations in the Hubbard Brook Experimental Forest, New Hampshire. *Ecology* 56(5): 1068-80.

Burton, T.M. and Likens, G.E. (1975) Salamander populations and biomass in the Hubbard Brook Experimental Forest, New Hampshire. *Copeia* 1975(3): 541-6.

Crawford, J.A. and Semlitsch, R.D. (2007) Estimation of core terrestrial habitat for stream-breeding salamanders and delineation of riparian buffers for protection of biodiversity. *Conservation Biology* 21:152-8.

Eaton, J.S., G.E. Likens, and F.H. Bormann. 1973. Throughfall and stemflow chemistry in a northern hardwood forest. *The Journal of Ecology* 61(2):495-508.

Feder, M.E. (1983) Integrating the ecology and physiology of plethodontid salamanders. *Herpetologica* 39(3): 291-310.

Gosz, J.R., G.E. Likens, and F.H. Bormann. 1972. Nutrient content of litter fall on the Hubbard Brook Experimental Forest, New Hampshire. *Ecology* 53(5):769-784.

Gosz, J.R., G.E. Likens, and F.H. Bormann. 1973. Nutrient release from decomposing leaf and branch litter in the Hubbard Brook Forest, New Hampshire. *Ecological Monographs* 43(2):173-191.

Heyer, W.R., M.A. Donnelly, R.W. McDiarmid, L.C. Hayek, and M.S. Foster. 1994. *Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians*. Smithsonian Institution Press, Washington.

Likens, G.E., F.H. Bormann, N.M.Johnson, D.W. Fisher, and R.S. Pierce. 1970. Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook Watershed-Ecosystem. *Ecological Monographs* 40(1):23-47.

Likens, G.E., F. H. Bormann, N.M. Johnson, and R.S. Pierce. 1967. The calcium, magnesium, potassium, and sodium budgets for a small forested ecosystem. *Ecology* 48(5):772-785.

Likens, G.E. and Buso, D.C. 2006. Variation in streamwater chemistry throughout the Hubbard Brook Valley. *Biogeochemistry* 78:1-30.

Lowe, W.H. (2003) Linking dispersal to local population dynamics: a case study using a headwater salamander system. *Ecology* 84(8): 2145-54.

Perkins, D.W. and Hunter, M.L. Jr. 2006. Effects of riparian timber management on amphibians in Maine. *The Journal of Wildlife Management* 70(3): 657-670.

Petranka, J.W. 1998. Salamanders of the United States and Canada. Smithsonian Institution Press, Washington, D.C., United States.

Pierce, B.A. (1985) Acid tolerance in amphibians. *BioScience* 35: 239-4.

Siccama, T.G., F.H. Bormann, and G.E. Likens. 1970. The Hubbard Brook Ecosystem Study: Productivity, Nutrients, and Phytosociology of the Herbaceous Layer. *Ecological Monographs* 40(4):389-402.

Stuart, S.N., J.S. Chanson, N. A. Cox, B.E. Young, A.S.L. Rodrigues, D.L. Fischman, R.W. Waller. 2004. Status and trends of amphibian declines and extinctions worldwide. *Science* 306:1783-1786.

Welsh, H. H. Jr. and Droege, S. 2001. A case for using plethodontid salamanders for monitoring biodiversity and ecosystem integrity of North American Forests. *Conservation Biology*. 15(3): 558-69.

Whittaker, R.H., F.H. Bormann, G.E. Likens, and T.G. Siccama. 1974. The Hubbard Brook Ecosystem Study: forest biomass and production. *Ecological Monographs* 44(2):233-254.

Wilson, J.D. and Dorcas, M.E. 2003. Effects of habitat disturbance on stream salamanders: implications for buffer zones and watershed management. *Conservation Biology* 17(3):763-771.

APPENDIX

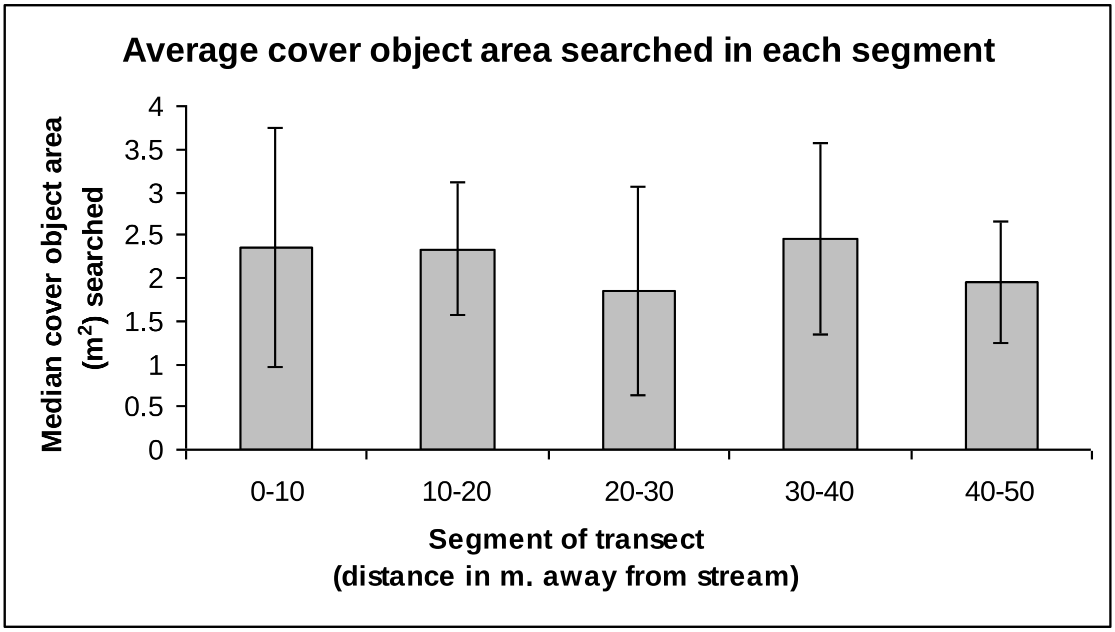

FIGURE 1. Graph of average cover object area along gradient of distance from stream.

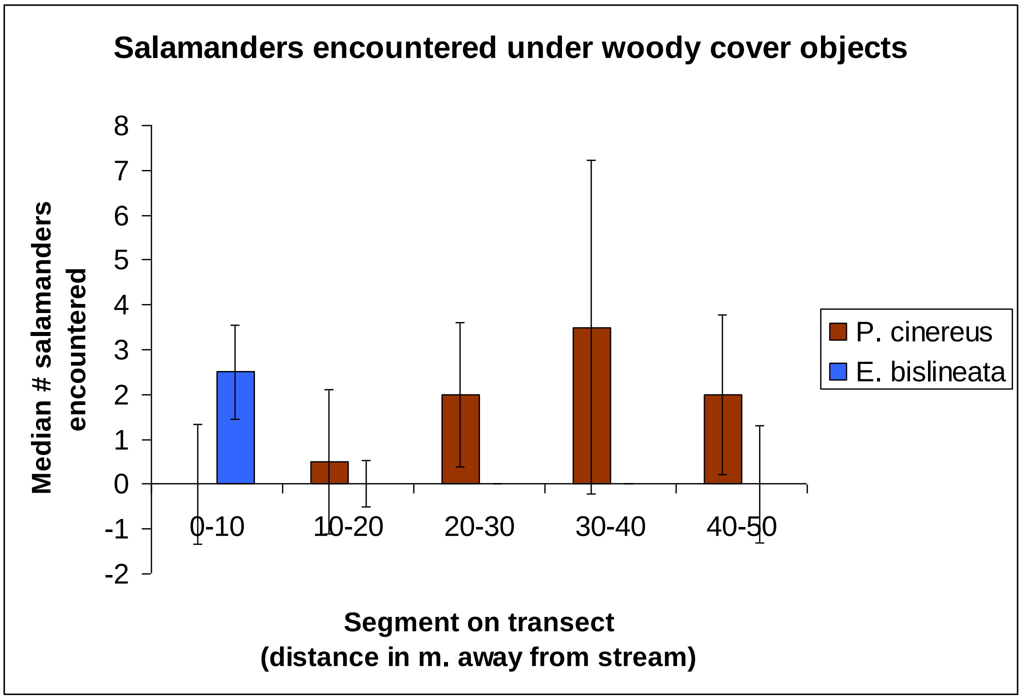

FIGURE 2. Graph of median salamanders encountered along gradient of distance from stream.

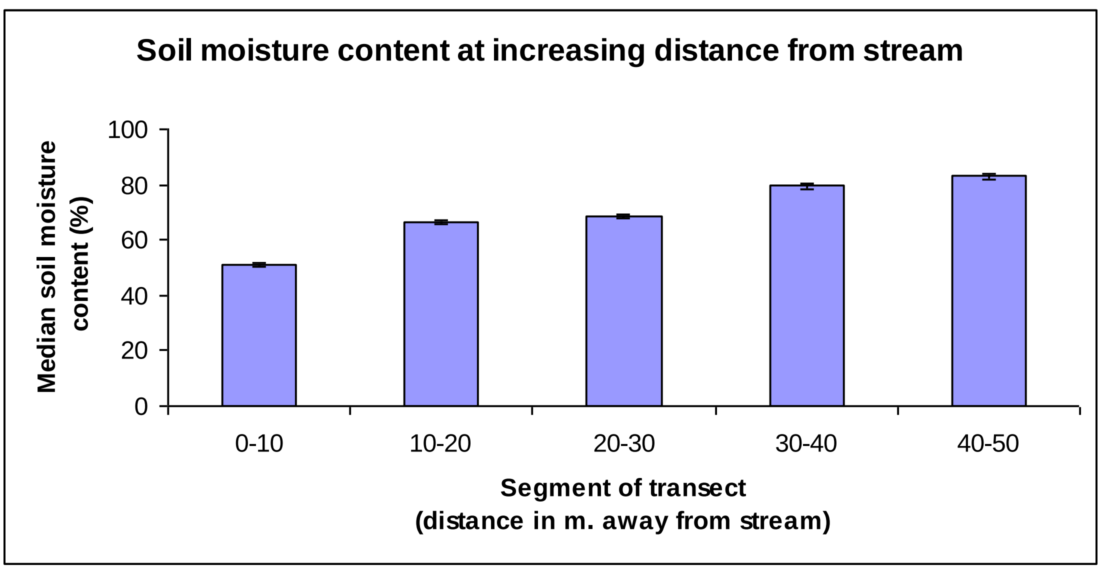

FIGURE 3. Graph of soil moisture content along gradient of distance from stream.

E. bislineata	**Section 0-10**	**10-20**	**20-30**	**30-40**	**40-50**
Transect 1	2	0	0	0	excluded
2	4	1	0	0	0
3	1	0	0	0	0
4	2	1	0	0	3
5	3	0	0	0	0
6	3	0	0	0	1
P. cinereus					
Transect 1	0	4	4	6	excluded
2	0	2	0	1	1
3	0	0	2	0	4
4	0	1	2	7	4
5	3	0	3	0	0
6	2	0	0	8	2

FIGURE 4. Raw data of salamanders encountered on transect surveys.