LOW-INTENSITY PRESCRIBED FIRE DOES NOT AFFECT SALAMANDERS IN AN OAK-HICKORY WOODLAND

by

Mary Elizabeth Dechant

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Thesis Committee:
Professor Paul Webb, Chair
Professor Earl Werner

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ABSTRACT

The impact of fire on salamanders and salamander habitat was assessed in ten plots (five burned and five unburned) surrounding an amphibian breeding wetland within a mature oak-hickory woodland in southeast Michigan. Area-constrained surveys were conducted in each plot between 11 March and 3 June 2006 in which leaf litter and woody debris were searched for salamanders. Leaf litter density, soil temperature, and soil moisture were also measured to assess habitat conditions in burned and unburned plots.

A total of 104 salamanders were captured during eleven sampling events: four blue-spotted salamanders (*Ambystoma laterale*), three spotted salamanders (*Ambystoma maculatum*), one eastern newt (*Notophtalmus viridescens*) and 96 red-backed salamanders (*Plethodon cinereus*). There was no significant difference in captures of salamanders in burned and unburned plots (Wilcoxon paired samples test, $p > 0.05$). There was also no statistically significant difference in measured habitat characteristics in burned and unburned plots (paired t-test, $p > 0.05$). The lack of a statistical difference in salamander captures and habitat structure between burned and unburned plots may be due to the patchy nature of the prescribed fire, which left greater than 75% of two plots unburned.

The practice of conducting low-intensity prescribed fire in oak-hickory woodlands does not appear to be harmful to salamanders when patches of land are left unburned. Further research should be conducted into the effects of fire specifically on *Ambystoma* salamanders and the eft phase of Eastern newts, as too few of these salamanders were captured to make reliable conclusions regarding their response to prescribed fire.

Introduction

Prescription fire is increasingly used in management plans to restore various types of woodlands to pre-settlement vegetative structure. However, the impact of these fires on non-target species is not well understood (Whelan 1995). In order for land managers to effectively balance the goals of vegetative restoration with wildlife conservation, the impacts on potentially vulnerable wildlife populations must be understood. Amphibians, for example, are sensitive to environmental changes and the widespread declines of these organisms compel land managers to thoroughly understand and minimize any potential source of stress on them. This study was undertaken as a first step in understanding how a small-scale restoration fire impacts populations of four species of salamanders in a nature preserve.

In 1997, land managers at the City of Ann Arbor's division of Natural Areas Preservation (NAP) developed a management plan for Black Pond Woods Park (BPWP). An integral component of this plan was the reintroduction of fire to the nature preserve, which is a late-successional oak-hickory forest dominated by pignut hickory, *Carya glabra*, and red oak, *Quercus rubra*, (ACRT, Inc. 1997). Historically, the ecosystem structure was maintained through periodic fires that resulted in clearing dense understory. This natural reduction of understory promoted the regeneration of oaks and other native vegetation. The suppression of fire in recent decades has altered forest structure by allowing more competitive, shade-tolerant trees to increase in abundance (Van Lear and Harlow 2000). The goal of reintroducing low-intensity fires to BPWP was to avoid this replacement of native oak and hickory (ACRT, Inc. 1997).

BPWP is known by park managers to be one of the few places in Ann Arbor where four species of salamanders reside. Before prescribed fire was implemented on a large scale at the park, land managers wished to understand whether burning would be detrimental to these animals. Salamanders are among the most abundant vertebrates in many forest ecosystems (David and Welsh 2004), reaching densities of 2950 salamanders/ha (Burton and Likens 1975*a*). They are an important food source, both as adults and larvae, for shrews, snakes, turtles, raccoons, aquatic insects, fish, and some birds (Burton and Likens 1975*b*, Harding 1997). Salamanders are also predators on both soil and aquatic invertebrates, and thereby exert an influence over detrital food webs, nutrient cycling, and decomposition rates (Burton 1976, Harding 1997, Wyman 1998). A decrease in salamander abundance due to prescribed burning at BPWP would cause shifts in food web ecology and affect ecosystem functions such as decomposition and nutrient cycling.

Studies on the impact of burning practices on salamanders have generally been inconclusive (Pilliod et al. 2003, Whelan 1995). Some studies suggest that fire suppression could potentially have negative impacts since many salamander species have evolved in historically fire-maintained forests (Russell et al. 1999, Pilliod et al. 2003, Bishop and Haas 2005). The restoration of fire to the park could therefore benefit salamanders by maintaining the forest vegetative structure and hydrology that form ideal salamander habitat.

However, prescription burning differs from natural fires and salamanders may lack the ability to respond appropriately to them (Bury et al. 2000, Pilliod et al. 2003). Natural fires generally occur in the hot, dry summer months when salamanders are less active while prescription fires tend to occur in cool, moist months of spring or fall when salamanders are engaged in breeding behavior (Schurbon and Fauth 2003). Natural fires often result in a patchy burn, while prescribed fires are often intended to completely burn the fuel load of a forest floor and remove unwanted vegetation (Bury 2004). If the prescribed fire is allowed to completely burn an area so that a high percentage of bare ground remains, critical salamander habitat components such as downed woody debris and leaf litter will be lost.

The importance of salamanders to forest food webs warrants an investigation into the effect of fire on this group. The goal of this study was to understand whether the low-intensity burning practices of NAP affect the distribution, migration, and breeding behavior of four species of resident salamanders. The information obtained was used to make recommendations to NAP for developing burn strategies that minimize impact to salamanders while still addressing the goals of vegetation management.

Methods

Site Description

BPWP is a 13.76-ha nature preserve with morainal topography located on the north side of Ann Arbor, Michigan (Figure 1, 42°18’17.59” 9N, 83°43’45.10” W). The park is managed by the Natural Areas Preservation (NAP) division of the City of Ann Arbor. The east side of the park borders the Leslie Golf Course, to the south is the Leslie Science Center, an environmental education center, and the west and north sides of BPWP border residential areas.

The center of the study site is Black Pond, a shallow precipitation-fed ephemeral wetland that measures 0.09 ha (ACRT, Inc. 1997). Early in the spring the wetland contains about 30 cm of water and often dries by late summer when the climate is hot and dry. This wetland serves as breeding habitat for spring peepers (*Acris crepitans*) and green frogs (*Rana clamitans*) as well as spotted salamanders (*Ambystoma maculatum*), blue-spotted salamanders (*Ambystoma laterale*), and Eastern newts (*Notophthalmus viridescens*).

Prescribed Fire

Ten plots (60 x 15 m) were established around the margin of the wetland. On 4 November 2005 NAP conducted a prescribed burn at BPWP in which alternate plots were burned; this pattern of burning was determined with a coin flip. A leaf blower was used to remove leaves and other flammable material to create the burn breaks between plots. Because the smoke from smoldering logs can be a nuisance for nearby areas, NAP took measures to keep woody material from burning. Woody debris was wetted down before the burn occurred, and leaves were cleared away from the perimeter of logs. Following the fire, a visual estimation of the percentage of bare ground remaining in each plot was conducted.

Salamander and habitat surveys

Salamander abundance in the burned and unburned plots was determined from mid-March through early June spanning spring migrations of spotted and blue-spotted salamanders to the breeding pool (Harding 1997). Surveys were conducted on warm, wet nights at a minimum temperature of 4º C. During each survey, area-constrained visual encounter surveys (Crump and Scott 1994) and leaf litter searches were performed in paired burned and unburned plots. For the leaf litter searches, a sub-sample of ten quadrats per plot was performed, in which the area within a 1-m^2 quadrat frame was thoroughly searched for salamanders. In each quadrat, all leaf litter was sifted and any logs in the quadrat were overturned. The number of salamanders found in the 10 quadrats was used to estimate density of salamanders in the leaf litter (salamanders/m^2 in leaf litter). After quadrat searches were complete, all woody debris in the plot was searched. The total number of salamanders captured in each plot was used to estimate woody debris density (salamanders/m^2 in woody debris). Each salamander was identified to species, measured (total length and snout-vent length, cm) with calipers, placed in a plastic bag and weighed (g) with a spring scale. The habitat in which each salamander was found (rock, log, leaf litter, bare ground) was recorded. Each salamander was returned to the same location in which it was found.

Habitat measurements (soil temperature, soil moisture, leaf litter mass, percent vegetative cover) were made once in 10 quadrats in each plot during the period of early May through early June.

Soil samples were collected using a 5 cm soil corer made from steel conduit. The samples were placed in a plastic bag, weighed (g), dried in a drying oven at 21º C for 48 hours, and weighed again to determine percent moisture of the sample.

Leaf litter samples were collected in order to estimate an index of litter abundance. In order to minimize the impact to salamander habitat, and because care was taken to preserve the integrity of this public park, small amounts of leaf litter were collected from each quadrat. A sharp stick was inserted into the litter at five points in each quadrat (the four corners and the center of the quadrat). The litter was placed in a plastic bag, dried, and weighed (g). The weight of the sample was used to generate an index of leaf litter abundance per sample (leaf litter dry mass/sample).

In each quadrat, the size (length x width, cm) of any woody debris was noted and percent vegetative cover was visually estimated (percent of quadrat covered by vegetation). Soil temperature (ºC) at 5 cm below the soil line was taken with a soil thermometer.

Statistical analysis

Because one burned and one unburned plot would be surveyed during each sampling event, plots were paired for statistical analysis. Weather conditions affect the surface activity of salamanders and ecological conditions, so pairing plots sampled on the same day would account for some of this variation. In addition, paired plots were adjacent to one another, so pairing allowed for plots with similar topography and vegetative characteristics to be compared to one another.

Salamanders were expected to be unevenly distributed across the study area, which would result in some quadrats containing no salamanders. This non-normal distribution of salamanders called for non-parametric statistical tests suited for analyzing data with a high proportion of quadrats containing 0 salamanders. Wilcoxon paired samples tests were used to assess differences in salamander densities between burned and unburned plots.

Differences in habitat parameters for each treatment were analyzed with paired t-tests.

Results

The prescription burning at BPWP did not completely burn some patches, and the degree of burn varied among plots (Table 1). This is consistent with the intended low-impact approach of burning employed by the management protocol. The degree of burning appeared to be affected primarily by dominant vegetation and the slope of the site, factors that should be explored further to better inform burn practices. Less than 25% of plot 1 burned completely because the dominant tree, American basswood (*Tilia americana*), has fire-tolerant leaves. Similarly, less than 25% of Plot 5 burned apparently because of the steep downward slope, which did not carry the fire well. In the other 3 burned plots, with low slope and less fire-tolerant vegetation, the fire carried well, resulting in burned patches covering at least 75% of the ground.

Overall, fire did not cause significant changes in the habitat parameters measured in this study (Table 1). The mean index of leaf litter abundance was higher in unburned plots, ranging from 6.71 – 13.65 g/sample in burned plots and 8.28 – 17.73 g/sample in unburned plots (Figure 1). These differences were significant (paired t-test, $p < 0.05$) for the first two pairs of plots sampled, but not the other three. A few days following the burn, the autumn leaf drop occurred. This added new leaf litter to all plots that probably reduced the differences between burned and unburned plots. Average soil temperatures were higher in burned plots, ranging from 9.9 – 15.05 ºC in burned plots and 9.8 – 14.5 ºC in unburned plots (Figure 2), but differences were not significant between burned and unburned plots (paired t-test, $p < 0.05$). There were also no significant differences in percent soil moisture between burned and unburned plots, which ranged from 19 – 35% and 21 – 30% respectively (Figure 3). Sample date did have a significant influence on soil moisture, soil temperature, and leaf litter abundance index, however, indicating that weather or other seasonal influences had a greater impact on habitat than this low-impact fire (ANOVA, $p < 0.01$).

Salamander captures totaled 104 during eleven sampling events; four blue-spotted salamanders, 3 spotted salamanders, one eastern newt and 96 red-backed salamanders were captured. Fifty-eight salamanders were captured in burned plots and 46 were captured in unburned plots (Table 2). Of these, the densities of salamanders captured in leaf litter did not differ significantly between burned and unburned plots (Figure 4; Wilcoxon paired samples tests, $p > 0.05$). Salamander densities under logs were not statistically compared since the amount of woody debris varied in each plot, and the amount of woody debris per plot was not quantified during salamander surveys. The percentage of burned area did not appear to have a large affect on salamander distribution. Overall, slightly more salamanders were captured in plots where the burn was most complete, but this was not a significant difference (Figure 5; regression analysis, $p > 0.05$).

Salamander densities varied according to sample date, as did habitat conditions, but there were no significant relationships between salamander densities and the measured habitat variables. The greatest densities of salamanders were observed during the wetter periods of mid-March through May, when temperatures were cool (7 ºC – 15 ºC). This suggests that the influence of climate on salamander behavior was stronger than that of low-impact burning.

In addition to these quantitative observations, salamanders were also observed migrating across burned and unburned habitat. Furthermore, on the evening of 31 March 2006, a breeding swarm of hundreds of spotted salamanders was observed in Black Pond, indicating that this important event was not hindered by burning. These observations of salamanders in the wetland were not used in the statistical analysis since they were observed outside the study plots.

Discussion

The prescribed fire at Black Pond Woods Park achieved the goal of a low-intensity burn intended to clear understory vegetation while minimally impacting salamander populations. In all five plots, the prescribed fires were patchy and unburned islands remained in each plot. These unburned patches were small (less than 25% of the total plot area) in three of the five plots, and large in two of the plots (more than 75% of the total plot area). As a likely consequence of this patchiness, habitat structure was not significantly altered by the fire, and salamander densities did not vary between burned and unburned plots or among plots with more burned area.

Several elements of NAP burning practices may have been important in minimizing negative impacts on salamanders. Wetting down woody debris to prevent the logs from burning and smoldering preserved this important habitat component and possibly offered refuge to salamanders and their prey. The timing of the fire before the annual leaf drop also may have been beneficial to salamanders. Although much bare ground was exposed immediately following the fire, the leaf drop refreshed the amount of leaf litter available to salamanders. In addition, the low intensity fire allowed for the preservation of unburned patches in moister habitats, which may have served as refuge for salamanders.

The findings of this study are consistent with other studies that found no impact of prescribed fire on salamanders when unburned habitat patches are retained (Ford et al. 1999, Mosely et al. 2003, Keyser et al. 2004).

deMaynadier and Hunter (1995) concluded that forest management practices may be compatible with amphibian conservation when a diverse array of microhabitat structures is maintained. In this study, NAP achieved the goal of restoring fire to the oak-hickory woodland while preserving suitable habitat for salamanders using a low-intensity fire.

In addition, burned habitat did not appear to act as a barrier to the migration behavior and dispersal of salamanders in this study. Several red-backed salamanders were captured on burned ground and spotted and blue-spotted salamanders were found migrating across burned habitat toward the ephemeral wetland. On 31 March 2006 a breeding swarm of hundreds of spotted salamanders was observed in the wetland, indicating that the prescribed fire did not prevent breeding activity from occurring. This supports the finding of Bishop and Haas (2005), who concluded that fire is essential to the Flatwoods salamander (*Ambystoma cingulatum*) since burning preserves the required vegetative structure of breeding wetlands. The observation of spotted salamanders engaging in breeding activity, as well as the capture of several *Ambystoma* salamanders on burned habitat, suggest that the fire did not have large impacts on this vulnerable group.

Had burn conditions been more intense, more of an effect on salamander distributions may have been observed. Mosely et al. (2003) found no overall difference between burned and unburned areas, but detected a negative correlation between salamander abundance and percent bare ground which increases after fires. Schurbon and Fauth (2003) found spotted salamanders only in plots completely burned twelve or more years previously, and Harding (1997) notes that this species is rarely found in recently burned areas. This study detected an insignificant increase in the amount of salamanders observed in plots with more burned area. Whether or not this observation was due to the availability of abundant unburned habitat in nearby sections of the study area cannot be determined from this project.

Definitive conclusions regarding the effect of fire on spotted salamanders, blue-spotted salamanders, and eastern newts are difficult to make from this study due to the very small numbers of these species collected. Drift fence and pitfall trap arrays set up during the breeding migrations may have resulted in higher sample sizes, but were not used to avoid the disruption of breeding behavior of the salamanders in this public park. Low sample sizes, particularly of *Ambystoma* salamanders, have been problematic for other studies on the effect of fire on salamanders (Jones 2000, Litt et al. 2001, Kilpatrick 2002, Moseley et al. 2003). In addition, some species, notably the mole salamanders (family Ambystomatidae) are under-sampled in fire studies, probably because they remain underground throughout most of the year. Additional studies should assess the effect of burning on reproductive success of *Ambystoma* salamanders, a study that would emphasize if the larval and post-metamorphosis stages of these species are affected by fire.

In conclusion, low impact prescription fires appear to have little impact on red-backed salamander density. However, due to the limited temporal and spatial scale of this study, land managers should conservatively interpret this finding of no impact of prescription fire on salamander densities. Future prescription burns should continue to preserve islands of suitable habitat to serve as refuge for salamanders. In situations in which these precautions are followed, this study suggests that prescription burning will not have a detrimental effect on salamander populations.

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References

ACRT, Inc. 1997. Black Pond Woods Management Plan. *Prepared for* The City of Ann Arbor, MI. Cuyahoga Falls, OH.

Bishop, David C. and Haas, Carole A. 2005. Burning trends and potential negative effects of suppressing wetland fires on Flatwoods salamanders. *Natural Areas Journal* 25:290-294

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

Burton, Thomas M. and Likens, Gene E. 1975a. Salamander populations and biomass in the Hubbard Brook experimental forest, New Hampshire. *Copeia* 1975:541-546

Burton, Thomas M. and Likens, Gene E. 1975b. Energy flow and nutrient cycling in salamander populations in the Hubbard Brook Experimental Forest, New Hampshire. *Ecology* 56:1068-1080

Bury, R. Bruce. 2004. Wildfire, fuel reduction, and herpetofaunas across diverse landscape mosaics in Northwestern forests. *Conservation Biology* 18: 968-975

Bury, R. Bruce, Major, Donald J. and Pilliod, David. 2000. Responses of amphibians to fire disturbance in Pacific Northwest forests: a review. *In* The role of fire in nongame wildlife management and community restoration: traditional uses and new directions. Proceedings of a special workshop. General technical report NE-288. US Forest Service, Northeastern Research Station, Newton Square, Pennsylvania.

Crump and Scott. 1994. Visual Encounter Surveys. Pp. 84-91. *In* Heyer, W. Ronald, Donnelly, Maureen A., McDiarmid, Roy W., Hayek, Lee-Ann C., and Foster, Mercedes S. (eds.), Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians. Smithsonian Institution Press, Washington and London.

David, Robert D. and Welsh, Hartwell H. 2004. On the ecological role of salamanders. *Annual Review of Ecological and Evolutionary Systems* 35:405-434

deMaynadier, Philip G., Hunter, Malcolm L. 1995. The relationship between forest management and amphibian ecology: a review of the North American literature. *Environmental Review* 3:230-261

Ford, W.M., Menzel, M.A., McGill, D.W., Laerm, J., McCay, T.S. 1999. Effects of a community restoration fire on small mammals and herpetofauna in the southern Appalachians. *Forest Ecology and Management* 114: 233-343

Harding, James H. 1997. *Amphibians and Reptiles of the Great Lakes Region*. The University of Michigan Press: Ann Arbor, MI.

Jones, Bob, Fox, Stanley F., Leslie, David M. Jr., Engle, David M., and Lochmiller, Robert L. 2000. Herpetofaunal responses to brush management with herbicide and fire. *Journal of Range Management* 53:154-158

Keyser, Patrick D., Sausville, David J., Ford, W. Mark, Schwab, Donald J., Brose, Patrick H. 2004. Prescribed fire impacts to amphibians and reptiles in shelterwood-harvested oak-dominated forests. *Virginia Journal of Science* 55:159-168

Kilpatrick, Eran S. 2002. The effects of prescribed burning and thinning as fuel reduction treatments on herpetofauna in the Upper Piedmont of South Carolina. MS Thesis, Clemson University.

Litt, Andrea R., Provencher, Louis, Tanner, George W., Franz, Richard. 2001. Herpetofaunal responses to restoration treatments of longleaf pine sandhills in Florida. *Restoration Ecology* 9:462-474

Moseley, Kurtis R., Castleberry, Steven B., and Schweitzer, Sara H. 2003. Effects of prescribed fire on herpetofauna in bottomland hardwood forests. *Southeastern Naturalist* 2:475-486

Pilliod, D.S., Bury, R.B., Hyde, E.J., Pearl, C.A., Corn, P.S. 2003. Fire and amphibians in North America. *Forest Ecology and Management* 178:163-181

Russell, Kevin R., Van Lear, David H., Guynn, David C. Jr. 1999. Prescribed fire effects on herpetofauna: review and management implications. *Wildlife Society Bulletin* 27:374-384

Schurbon, J. M. and Fauth, J. E. 2003. Effects of prescribed burning on amphibian diversity in a southeastern US National Forest. *Conservation Biology* 17:1338-1349

Van Lear, DH and Harlow, RF. Fire in the Eastern United States: Influence on Wildlife habitat. *In* The Role of Fire in Nongame Wildlife Management and Community Restoration: Traditional Uses and New Directions USDA General Technical Report NE-288.

Whelan, Robert J. 1995. The ecology of fire. Cambridge University Press, Great Britain.

Wyman, Richard L. 1998. Experimental assessment of salamanders as predators of detrital food webs: effects on invertebrates, decomposition, and the carbon cycle. *Biodiversity and Conservation* 7:641-650

Table 1. Mean (± 2 SE) of leaf litter mass index, soil moisture, and soil temperature in burned and unburned plots. Burned and unburned plots sampled on the same day were paired for statistical analysis. Each plot was surveyed once, and habitat conditions were measured in 10 quadrats in each plot (n = 10). Leaf litter mass index was calculated by measuring the dry mass of leaves collected from 5 points within each quadrat. Percent soil moisture was calculated by dividing dry mass / wet mass of soil collected with a 5 x 2.5 cm soil corer. Soil temperature was taken at 5 cm below the soil line.

Plot	Treatment	% Burned Area	Mean Leaf Litter Abundance Index (leaf litter dry mass per sample point, g / 5)	Mean Percent Soil Moisture (g)	Mean Soil Temp. (ºC)
1	**burned**	**<25**	**13.65 ± 0.94**	**0.22 ± 0.01**	**14.10 ± 0.35**
2	**unburned**	**--**	**8.85 ± 1.10**	**0.20 ± 0.01**	**14.50 ± 0.27**
3	**burned**	**75**	**6.84 ± 0.44**	**0.21 ± 0.02**	**15.60 ± 0.34**
4	**unburned**	**--**	**8.28 ± 0.67**	**0.35 ± 0.07**	**14.0 ± 0.37**
5	**burned**	**<25**	**11.19 ± 1.20**	**0.30 ± 0.01**	**12.8 ± 0.33**
6	**unburned**	**--**	**17.73 ± 0.88**	**0.30 ± 0.02**	**9.80 ± 0.13**
7	**burned**	**75**	**10.51 ± 1.99**	**0.28 ± 0.01**	**9.90 ± 0.1**
8	**unburned**	**--**	**11.13 ± 1.29**	**0.27 ± 0.01**	**14.1 ± 0.28**
9	**burned**	**75**	**6.71 ± 0.62**	**0.26 ± 0.01**	**15.05 ± 0.54**
10	**unburned**	**--**	**10.78 ± 1.03**	**0.21 ± 0.01**	**14.10 ± 0.1**

Table 2. Mean salamander density (± 2 standard error) in woody debris and leaf litter in burned and unburned plots. During each of eleven sampling events, one burned and one unburned plot was surveyed. Because plots were chosen randomly for searching, the number of times a plot was sampled varies and is shown here. To determine mean salamander density under woody debris, all logs in a plot were overturned and the number of salamanders was divided by plot size (15 m x 60 m; n = 1). To determine salamander density in leaf litter, the leaf litter was searched in 10 quadrats (1 m x 1 m) per plot and the number of salamanders was divided by 10 m (n = 10). Plot 8 was not searched for salamanders due to a dense covering of raspberry bushes that prevented access to the plot.

Plot	Treatment	Mean Salamander Density, Woody Debris (salamanders / 15 x 60 m)	Mean Salamander Density, Leaf Litter (salamanders / 10 m)	Number of surveys
1	burned	0.001	0	1
2	unburned	0.0345 ± 0.067	0.20 ± 0.10	2
3	burned	0.003	0.1	1
4	unburned	0.005 ± .004	0.10 ± 0.20	3
5	burned	0.002 ± .002	0.13 ± 0.27	3
6	unburned	0.003 ± 0.004	0	3
7	burned	0.004 ± 0.004	0.27 ± 0.44	3
8	unburned	not sampled	not sampled	0
9	burned	0.004 ± 0.003	0.10 ± 0.20	3
10	unburned	0.001 ± 0.001	0.10 ± 0.12	3

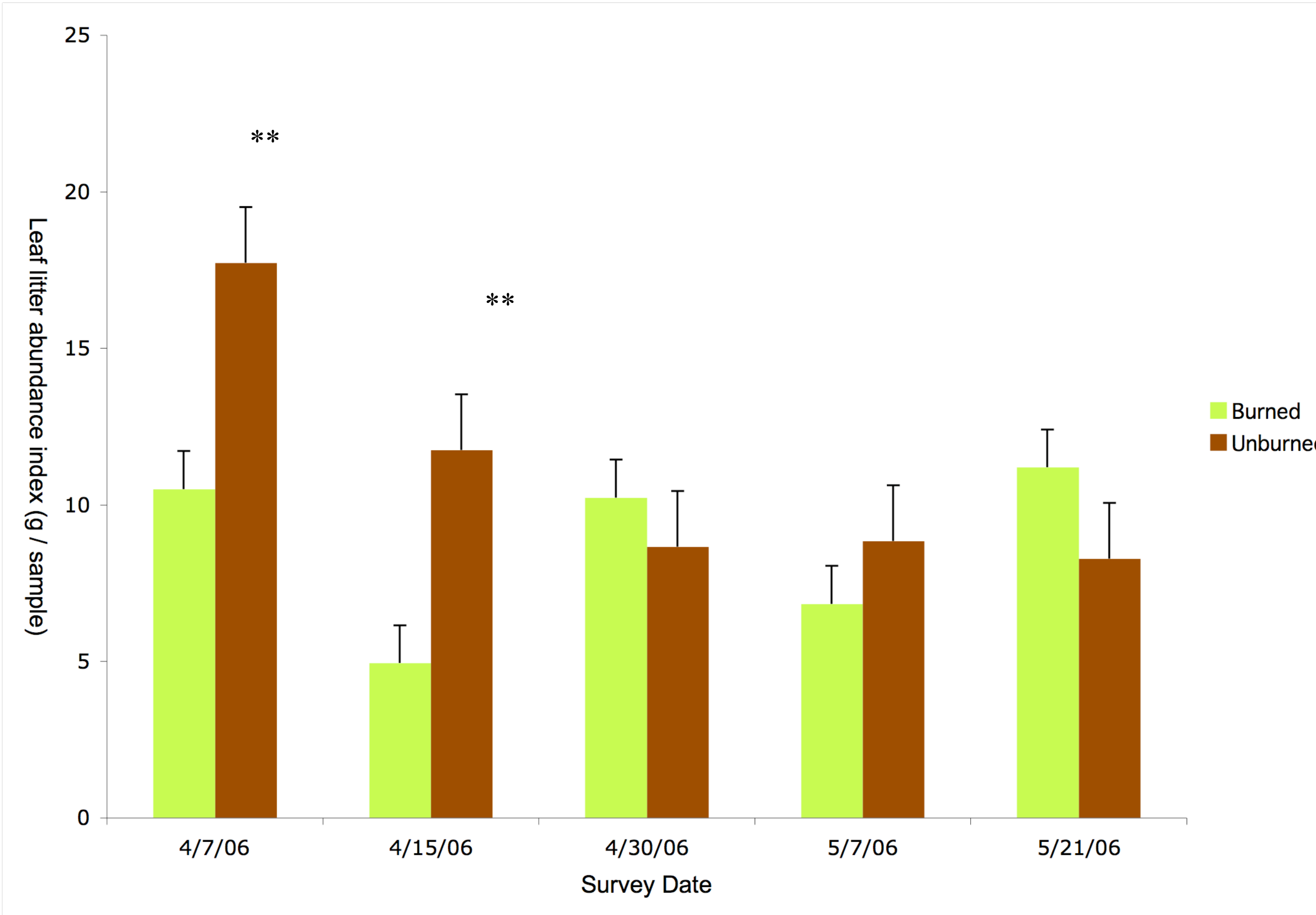

Figure 1. Mean leaf litter abundance index estimated for each sampling event in burned and unburned plots. Ten leaf litter samples per plot were collected from 10 quadrats in one burned and one unburned plot in five sampling events. Asterisks indicate significant results of paired t-tests ($p < 0.05$) for burned and unburned plots sampled on the same day.

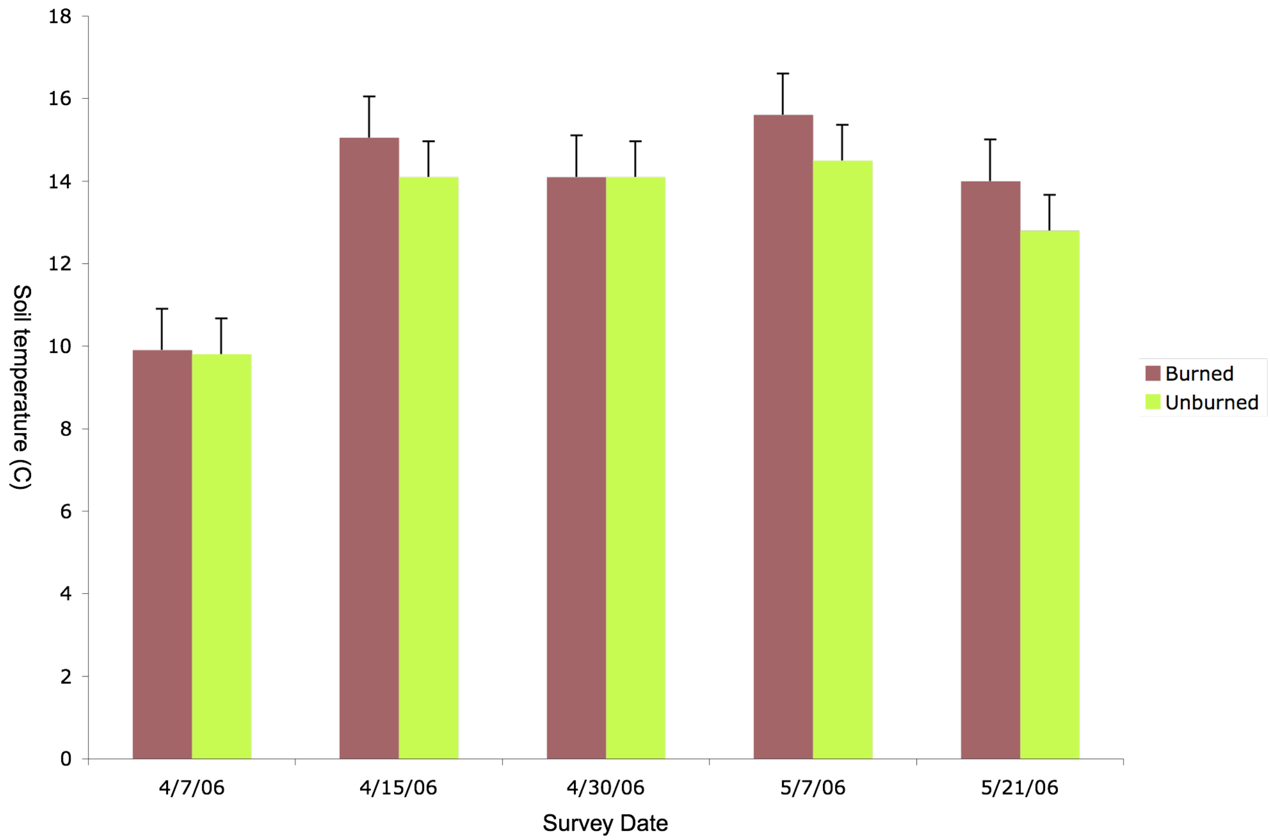

Figure 2. Mean soil temperature (C) estimated for each sampling event in burned and unburned plots (sample size = 10). Soil temperature was measured 5 cm below the soil line in 10 quadrats in one burned and one unburned plot during five sampling events. The results of paired t-tests testing differences between burned and unburned plots were not significant for any pair ($p > 0.05$).

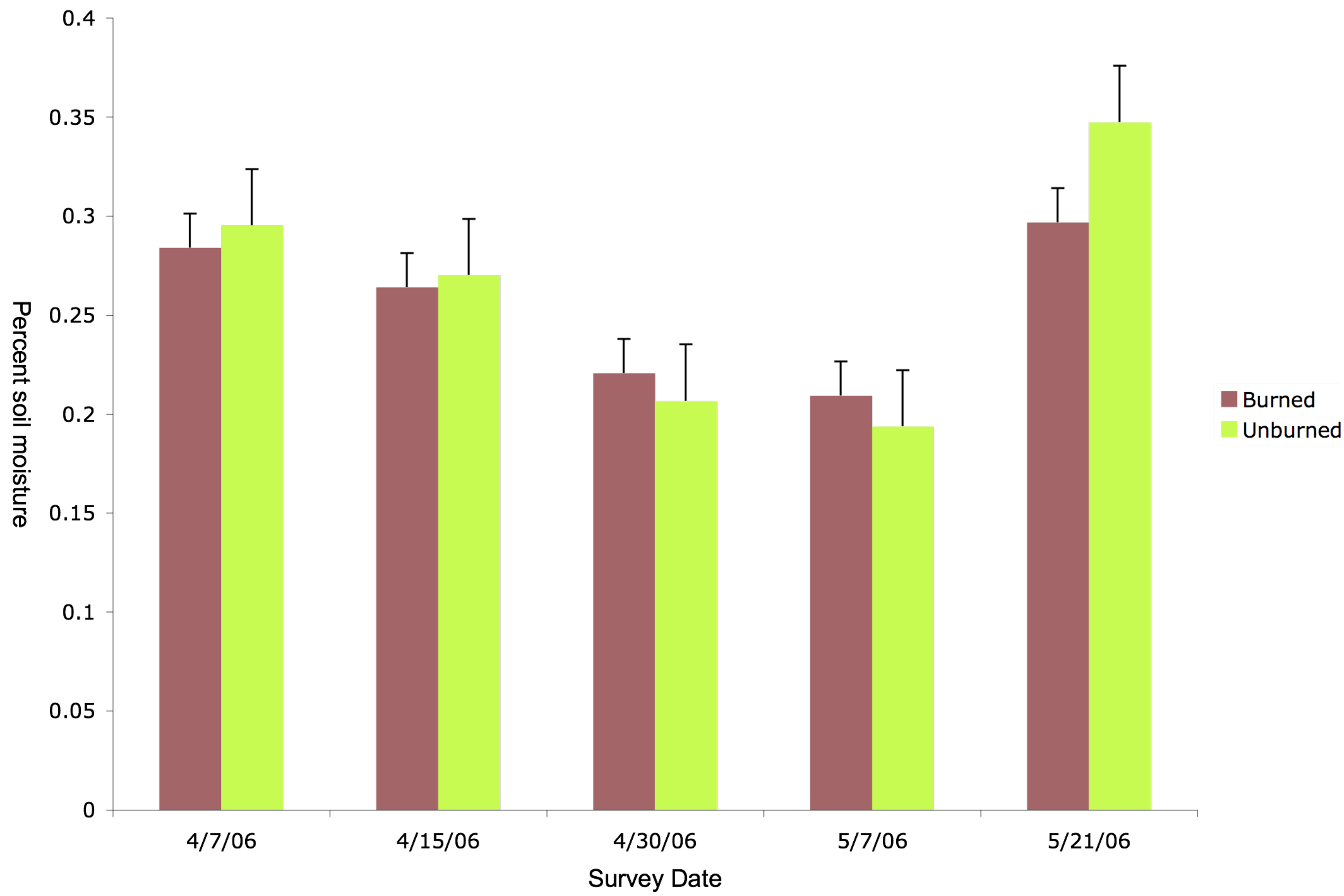

Figure 3. Mean percent soil moisture estimated in burned and unburned plots during each sampling event. Ten soil samples per plot were collected in a 5 x 2.5 cm soil corer, weighed, dried, and weighed again to estimate percent soil moisture. Soil was collected in 10 quadrats in one burned and one unburned plot during five sampling events. The results of paired t-tests testing differences between burned and unburned plots were not significant for any pair ($p > 0.05$).

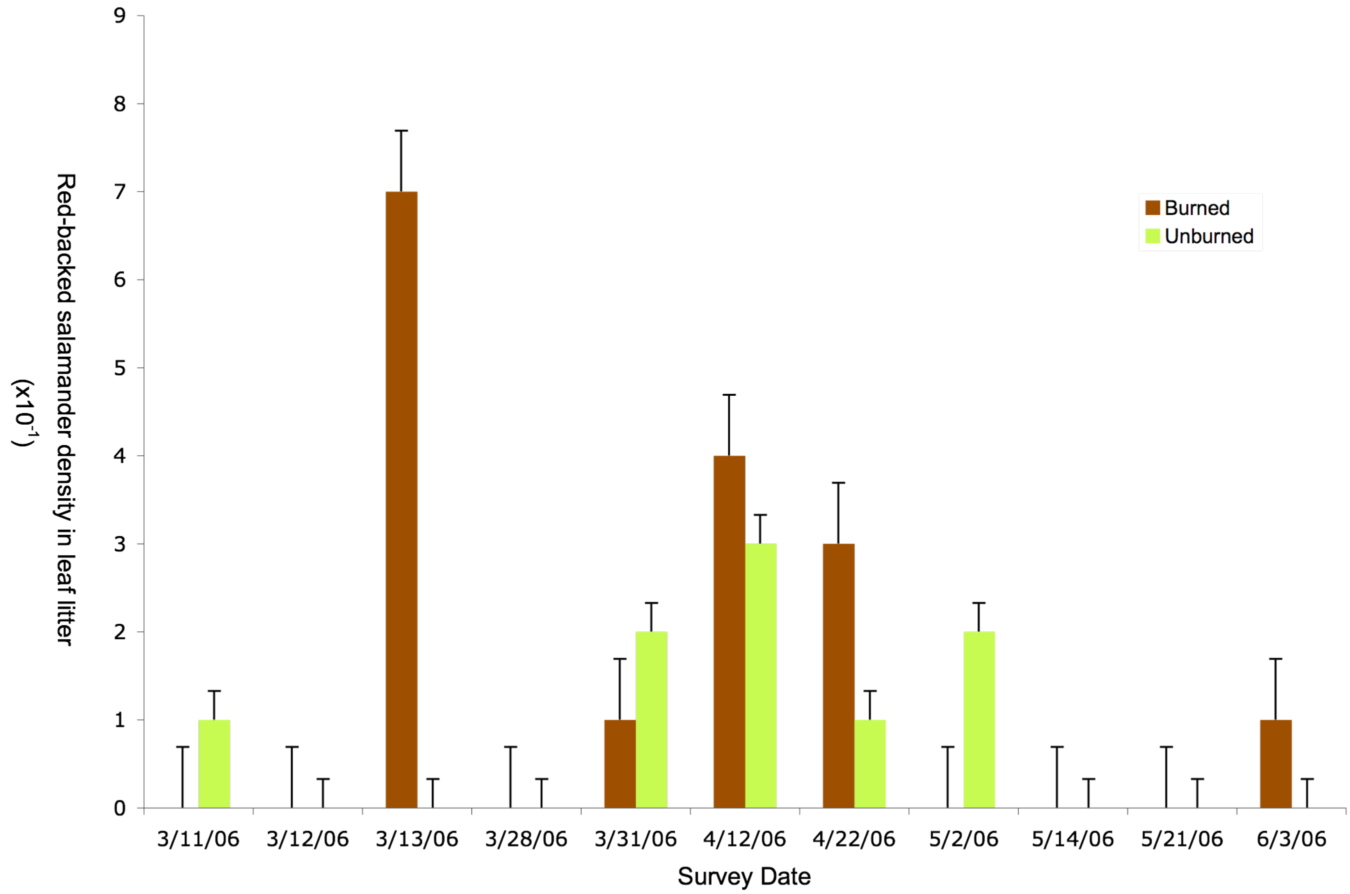

Figure 4. Densities of salamanders in leaf litter estimated for each sampling event. Vertical bars show ±2 standard error. In each plot, the leaf litter in 10 1m^2 quadrats was searched (sample size = 10). Results from Wilcoxon paired samples tests indicated that differences in densities between burned and unburned plots for each sampling event were not significant ($p > 0.05$, ranging from 0.07 - 1).

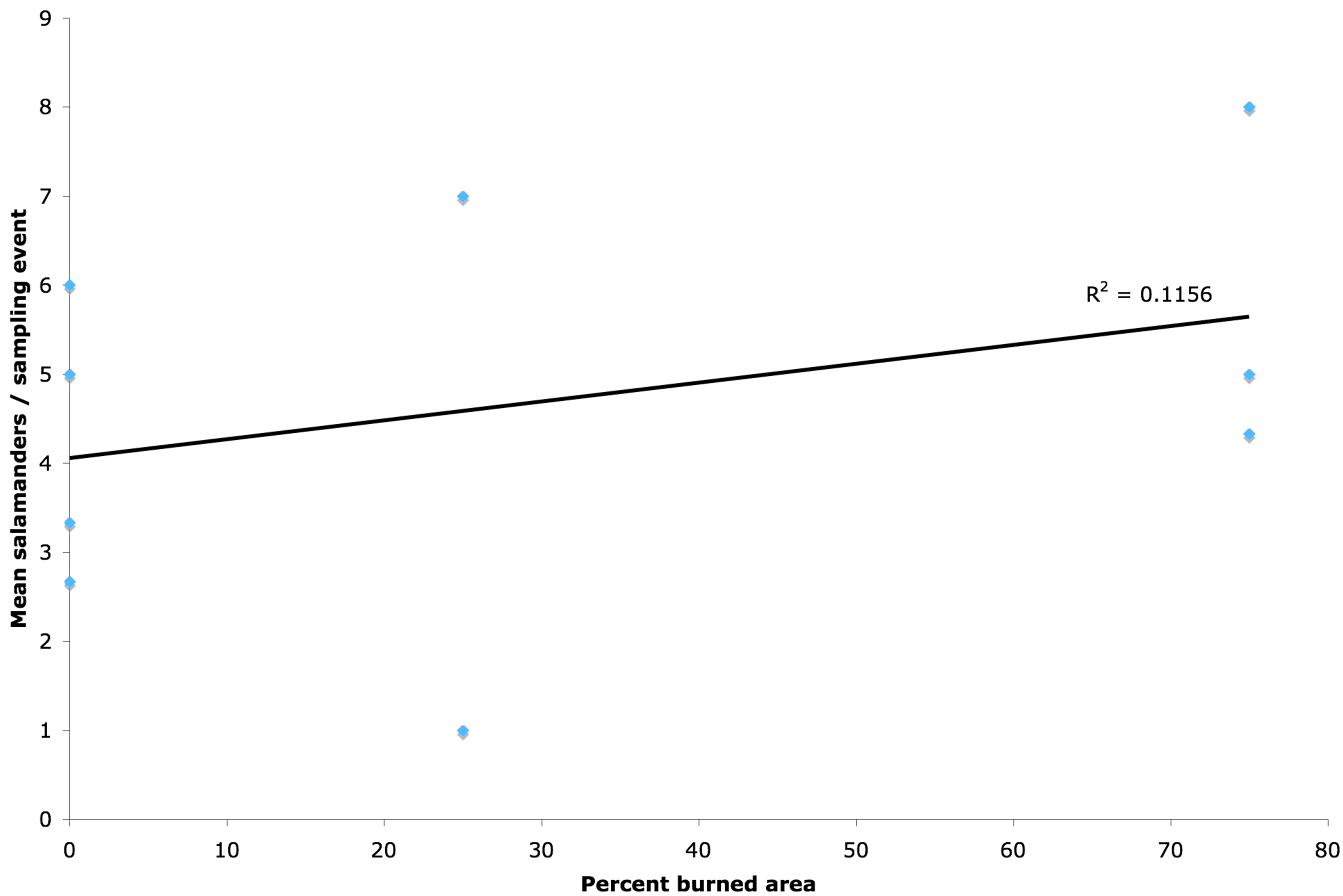

Figure 5. The effect of percent burned area on mean salamander density per sampling event. Percent burned area was assessed immediately following a low-intensity fire and was determined to be either 0 (no burn), less than 25% (patchy burn), or greater than 75% (complete burn). The mean number of salamanders captured during each sampling event is plotted here against these burn categories.