Spring 5-2016

Effects of Light Pollution on Habitat Selection in Post-Metamorphic Wood Frogs and Unisexual Blue-Spotted Salamanders

Abigail B. Feuka
University of Maine

EFFECTS OF LIGHT POLLUTION ON HABITAT SELECTION IN POST-METAMORPHIC WOOD FROGS AND UNISEXUAL BLUE-SPOTTED SALAMANDERS

by

Abigail B. Feuka

A Thesis Submitted in Partial Fulfillment
of the Requirements for a Degree with Honors
(Wildlife Ecology)

The Honors College

University of Maine

May 2016

Advisory Committee:

Dr. Malcolm L. Hunter, Jr., Libra Professor of Conservation Biology
Dr. Aram J.K. Calhoun, Professor of Wetland Ecology
Dr. Michael T. Kinnison, Professor of Evolutionary Applications
Dr. Mark Haggerty, Rezendes Preceptor for Civic Engagement
Kristine E. Hoffmann, Ph.D. Candidate in Wildlife Fisheries and Conservation Biology

Abstract

Light pollution is known to be problematic for many nocturnal organisms, but our understanding of its effects on amphibians is relatively poor. This is particularly true for recently metamorphosed, as their small size makes them difficult to track. Our objectives were to determine if wood frogs (*Lithobates sylvaticus*) and unisexual blue-spotted salamanders (*Amybostoma laterale x jeffersonianum*) select deciduous or coniferous leaf litter and if this behavior was affected by artificial light. We conducted choice experiments using 42 salamanders and 46 frogs placed in covered outdoor mesocosms. Each mesocosm was divided into half coniferous and half deciduous leaf litter and its underlying soil. Animals were given one night to choose a substrate, and their positions were recorded the next morning. We then conducted lighted trials in the same mesocosms, with a flashlight illuminating one substrate one night, and the other substrate the following night. Frogs did not have a leaf litter preference ($p>0.20$), and did not show a preference when either substrate was illuminated ($p>0.20$ with deciduous lit and $0.10<p<0.20$ with coniferous lit). Salamanders strongly preferred deciduous litter ($p<0.001$). This preference ratio changed in illuminated deciduous trials ($p<0.001$), but the majority of salamanders still chose illuminated deciduous litter (31 of the 43). Salamanders chose coniferous litter more often when it was illuminated than in substrate trials with no illumination ($p<0.001$). Our results suggest that artificial lighting could attract these salamanders to substrates they would not normally select, but more research is needed to understand the basis for the observed patterns.

For Kris Hoffmann, who mentored me as an ecologist
and introduced me to the wonderful world of vernal pools.

Acknowledgements

This thesis was the collaborative effort made possible by many people's time, effort, and support. This research was generously funded by the Maine Experimental Program to Stimulate Competitive Research (EPSCoR) and the Charlie Slavin Research Fund from the University of Maine Honors College. I'd like to thank my thesis committee for their wisdom, guidance, and full confidence in me from throughout the entire process. I thank the University of Maine Department of Wildlife, Fisheries, and Conservation Biology faculty for shaping me as an ecologist and providing me with the education and skills necessary to complete this project.

I had a great deal of help from volunteers constructing and deconstructing mesocosms. These volunteers included Brittany Cline, Samantha McGarrigle, Emma Betterly, Luke Groff, Randi Jackson, Audrey Dean, Thomas Hastings, and Hope Eye. Emily Feuka also helped record animal locations for a large majority of the trials, and I'd like to thank her for spending her visit to Maine helping her sister search for amphibians in cattle tanks. The support of my friends and family has been instrumental to this project, as they constantly offered encouragement and moral support.

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Introduction

With the rapid spread of urban development into more natural areas, research studying its ecological effects has become more prevalent in the past decade, but current research on the effects of light pollution emitted from these urban areas has remained relatively sparse. The massive amount of light emitted into our night sky illuminates both urban areas as well as nearby natural areas. That said, light pollution tends to be quantified by the number of humans affected and is often measured in terms of what Longcore and Rich (2004) refer to as "astronomical light pollution," or in how many astronomic features humans can see from a given point. Cizano et al. (2001) reported that 99 percent of the United States and European Union population, and about two-thirds of the world population, live in areas where the night sky is considered polluted with artificial light (Cinzano et al. 2001). However, these are anthropocentric views on light pollution, and the effects of "ecological light pollution," i.e., light that affects the natural photoperiod in an ecosystem, tend to be overlooked (Longcore and Rich 2004). Humans are generally accustomed to nighttime exposure to artificial light, but populations of other organisms that have historically lived under dark skies at night could change their behavior as a result of this artificial illumination. For example, artificial light has been shown to suppress immune responses in Siberian hamsters (*Phodopus sungorus*), inhibit mating in geometrid moths (*Mamestra brassicae*), and improve foraging conditions for number of frog species, all of which could have an affect on evolutionary fitness (Perry et al. 2008; Bedrosian et al. 2011; van Geffen et al. 2015).

Light pollution exists in two forms: point source and urban sky glow. Point sources of light, such as porch lights and street lamps, are direct light sources and fragment darkness across the landscape. Urban sky glow, the accumulation of all the artificial outdoor light in an area creating background illumination, brightens the entire sky beyond its natural levels (Albers and Duriscoe 2001). Some of these artificial light sources can be over one million times brighter than the moon or stars, and may drastically alter the nighttime environment (Wise and Buchanan 2006). Many protected natural areas are subject to both types of light pollution, in the form of building lights on nearby buildings as well as in their proximity to urban areas, making this a problem that spreads across both human-dominated and even more remote landscapes.

Some animals' behavioral patterns change with a change in nighttime light. For example, the foraging habitats of bats, birds, rodents, and even marine mammals have been found to change with the lunar cycle (Brigham and Barclay 1992; Gannon and Willig 1997; Brigham et al. 1999; Horning and Trillmich 1999; Dawson et al. 2001; Navara and Nelson 2007). The loggerhead sea turtle is a highly publicized case of the effects of artificial light. Instead of orienting toward the sea, hatchling turtles were found to travel inland toward artificial light (Salmon and Wyneken 1987; Witherton and Bjorndal 1990; Witherington 1992). Beyond this case, however, light pollution research on amphibians and reptiles is relatively lacking (Perry et al. 2008). This is a concern for amphibians especially, as many require cool, moist conditions out of direct sunlight and thus tend to be nocturnal.

The known effects of light on amphibians vary among different species, age classes, and different sources of light. Buchanan (1993) found that gray treefrogs (*Hyla chrysoscelis*) were less likely to detect and consume prey under red-filtered light and two intensities of white light than under ambient moonlight. The squirrel treefrog's (*Hyla* *squirella*) ability to detect prey, however, was enhanced using artificial light (Buchanan 1998). Green frogs (*Lithobates clamitans*) made fewer mating calls and moved more frequently when a flashlight was shone on them (Baker and Richardson 2006). However, Mazerolle et al. (2005) found that green frogs, American toads (*Anaxyrus americanus*), spring peepers (*Pseudacris crucifer*), and wood frogs (*Lithobates sylvaticus*) were more likely to stop in roadways when approached by vehicle headlights, increasing their risk of automobile-related mortality. A comparison of these studies suggests that frog responses to artificial light may depend on the source, intensity, movement, or speed of appearance of light (if it turns on suddenly like a light switch or fades in like moonlight).

Salamander movements may be influenced by the presence of light. Spotted salamanders (*Ambystoma maculatum*), blue-spotted salamanders (*Ambystoma laterale*), and unisexual blue-spotted salamanders (*Ambystoma lateral x jeffersonianum*) make their migrations from vernal pools on rainy nights and, like frogs, tend to respond to oncoming vehicle lights by stopping in the roadway (Mazerolle et al. 2005). Juvenile red-spotted newts (*Notophthalmus viridescens*) use a light-dependent magnetic compass to migrate to and from their natal ponds, and this homing behavior is disrupted when the newts are exposed to yellow-spectrum outdoor lighting (Phillips and Borland 1994; Fischer et al. 2001; Phillips 2002). Foraging behavior may also be affected: unpublished data by Wise and Buchanan suggest that red-backed salamanders (*Plethodon cinereus*) forage less in brighter areas than in darker ones, though they may be able to see prey more easily in the illuminated area.

Some larval amphibians are attracted to natural and artificial light. Beiswenger (1977) found that the distribution and activity of American toad tadpoles throughout the day are closely related to changes in light; in particular, tadpoles were more dispersed and less active on cloudy days. Spotted salamander larvae were found to choose illuminated water over dark water in laboratory tests (Schneider 1968). Anderson (1972) found one subspecies of larval long-toed salamanders (*Ambystoma macrodactlyum sigillatum*) to be photopositive, or attracted to light, until it metamorphosed and another subspecies' larvae (*A. m. croceum*) to be significantly more photopositive than adults. Larval marbled salamanders have also been found to be increasingly photonegative with age (Marangio 1975). Though some species are attracted to light in the larval stage, it has been found that prolonged exposure to light can either positively or negatively affect the growth and development of larval amphibians, depending on the species (Eichler and Gray 1976; Gutierrez et al. 1984; Delgado et al. 1987; Edwards and Pivorun 1991; Lee et al. 1997; Ruchin 2003). Research on the effects of light pollution on the "metamorph" phase is sparse compared to research on adults and larvae.

In recent years, research on the effects of urbanization on amphibians has become more prevalent. A review of 32 urban studies on North American amphibians found that as a whole, amphibians respond negatively to urbanization in terms of growth and development, movement patterns, habitat use, and breeding behavior (Scheffers and Paszkowski 2012). This threat is especially apparent when it comes to smaller breeding areas, like vernal pools. In southern Maine alone, Baldwin and deMaynadier (2009) found that over 50% of the potential breeding pools they delineated were not represented in the National Wetlands Inventory, and thus are at risk of urban encroachment. Many studies have shown that juvenile vernal pool amphibians tend to avoid large, open-canopy clearings created by development and clearcuts (deMaynadier and Hunter 1999;

Rothermel and Semlitsch 2002; Vasconcelos and Calhoun 2004; Patrick et al. 2006). This pattern is likely due to the increased risk of desiccation and predation, and possibly due to high levels of natural and artificial nighttime light.

On a smaller scale, vernal pool amphibians tend to select microhabitat that provides multiple levels of cover. Adult wood frogs select closed-canopy, along with forested wetlands with shady, moist microhabitats (Baldwin et al. 2006; Blomquist and Hunter 2010). Patrick et al. (2008) found that juvenile wood frogs do not exhibit fine-scale habitat selection during their emigration phase, but they did select areas with coarse woody debris and more vegetation during their settling phase**.** Blue-spotted salamanders and spotted salamanders have been shown to select cool, closed-canopy habitats with deeper leaf litter, more coarse woody debris, and less herbaceous cover (Ryan and Calhoun 2014; Montieth and Paton 2006). Spotted salamanders use leaf litter and soil as cues that influence small-scale habitat selection when given the choice between forest and grassland substrates (Rittenhouse et al. 2004; Belasen et al. 2013; Ousterhout et al. 2014). Though these amphibians spend a large portion of their adult lives on the forest floor among both coniferous and deciduous litter, little is known about how leaf litter factors into habitat selection.

Human development around vernal pools has the potential to affect multiple aspects of amphibian habitat, including leaf litter composition, and thus regulations have been put in place to manage direct impacts to pools and the immediate terrestrial habitat around them. State and federal governments regulate a small proportion of vernal pools, but they still allow some development around even these protected pools (Clean Water Act, Section 404; Maine Natural Resources Protection Act, Chapter 335, section 9). Point sources of light from development just outside this protected zone could affect the amphibians that inhabit these pools. Migrating individuals especially could be affected, as ambystomatid salamanders have been documented to travel an anywhere from 67 to 364 meters from their pools (Ryan and Calhoun 2014; Montieth and Paton 2006; Hoffmann, unpublished data) and wood frogs from 65 to 340 meters (Regosin et al. 2003; Baldwin et al. 2006). This means they could encounter illuminated substrate both outside and inside of the protection buffer during migration.

Our goal was to determine what effect point sources of light pollution have on the habitat selection of metamorph amphibians emerging from vernal pools. We attempted this by testing two hypotheses. First, we predicted that without artificial light, both the frogs and salamanders would select deciduous litter to coniferous litter, as it tends to create more humid conditions. Secondly, we expected both species would avoid artificially illuminated substrate, as they are nocturnal, and in the blue-spotted salamander's case, fossorial, and typically make substrate selections in the dark.

Methods

Experimental Design

We collected 42 metamorph blue-spotted salamanders and 46 wood frogs using drift fences surrounding 2 vernal pools in Orono, Maine from 13 August 2014 to 27 August 2014. The amphibians were housed in 5-gallon buckets with wet leaf litter and ventilated lids between trials (up to 3 days total), with four animals per bucket. We measured snout to vent length for all metamorphs, as well as total length for all salamanders collected.

We conducted choice experiments to determine whether metamorphs select deciduous or coniferous leaf litter. We used seven terrestrial mesocosms constructed from circular cattle tanks, 208 cm in diameter and 65 cm deep. The mesocosms were placed in a mixed coniferous-deciduous forest and covered at night with three meter by three meter clear perforated plastic tarps. Half of each tank contained a mix of red maple, red oak, and white birch leaf litter (*Acer rubrum, Quercus rubra,* and *Betula papyrifera*) three to five cm deep and one cm of its underlying soil, and the other half contained the same amounts of eastern white pine (*Pinus strobus*) leaf litter and its underlying soil (Belasen et al. 2013). These tree species were chosen because they are abundant around the vernal pools from which the metamorphs were collected. The leaf litter and soil were collected from homogenous plots around the pools (Belasen et al. 2013). An opaque cardboard divider was hung between the two leaf litter types, leaving 1 cm of space above the substrate for the animals to travel underneath (Anderson 1972).

To begin each trial, four metamorphs of the same species were placed in the center of each of seven mesocosms, oriented along the line between deciduous and coniferous litter, between 1900 and 2000 hours. For the duration of the trials, four mesocosms contained only frogs and three contained only salamanders. The animals were given 10 minutes to acclimate to their surroundings. The salamanders acclimated under a one cm tall plastic lid. The frogs were placed in plastic lids with a mixture of one tablespoon of fluorescent powder (DayGlo ECO Pigment™, DayGlo Color Corp., Cleveland, OH) and one teaspoon of mineral oil (Aspen Veterinary Resources®, Ltd., Kansas City, MO) with a 10 cm by 10 cm piece of plastic window screen mesh placed over the powder dish to prevent them from leaving the tray during the acclimation period

(Graeter et al. 2008). After the acclimation covers were removed, the plastic tarp was placed over the tank. The following morning between 0700 and 0900 hours, we located frogs in the mesocosm by shining an ultraviolet light on the leaf litter to reveal their powder trails. We located salamanders by gently removing leaves from the tank. Metamorphs located on the line between coniferous and deciduous leaf litter were counted in the portion in which their heads were located (Anderson 1972). Once each animal was located, it was returned to a holding bucket until the next trial at dusk.

After an initial night of habitat choice experiments, the same animals were used in two more night trials to determine if artificial light affected habitat selection. These tests used the same design as the habitat choice experiments, with the addition of a flashlight (Eveready® LED handheld flashlights: Model 5109L, Series 908D/908A, 1,680 cd intensity, 25 lumens, six-volt battery) attached to the side of the cattle tank approximately 50 cm above the leaf litter, illuminating half of the tank at 14.7 lux (1.7 m^2) (Anderson 1972; Marangio 1975). We chose to use LED lights due to their popular use in outdoor light fixtures. We placed the flashlight on either the coniferous or deciduous side of the tank one night, and switched to the opposite side the next night. Half the mesocosms had the deciduous litter illuminated the first night, and the other half had the coniferous litter illuminated the first night. After the three nights of trails, the metamorphs were released back to their respective pools. Figure 1 depicts the three-night trial sequence used on one set of animals. Shaded ambient high and low temperatures were recorded for each 24-hour period during the experiment.

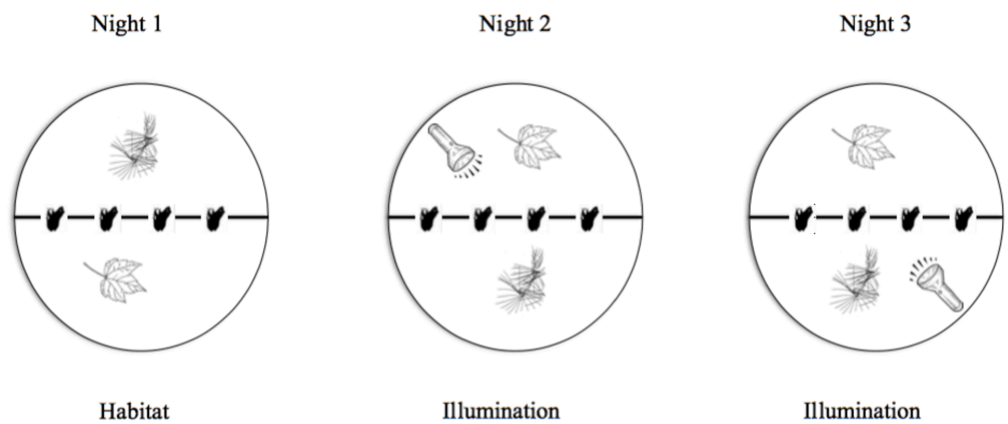

Figure 1. The three-night trial sequence in one mesocosm. Night 1 was a dark habitat selection trial and nights 2 and 3 were illuminated selection trials with either the coniferous or deciduous substrate illuminated.

Statistical Analysis

We used a chi-square goodness of fit test to detect a deviation from an expected 1:1 ratio between metamorphs found in deciduous litter and coniferous litter in both habitat and illuminated trials (Anderson 1972; Merangio 1975). Once we found an observed ratio between deciduous and coniferous selection, we used another chi-square goodness of fit test to determine if there was a difference in observed selection ratios in illuminated trial and these ratios from habitat (or control) trials. We considered p-values less than 0.05 to be statistically significant in our analyses.

Results

The mean snout to vent length was 12.8 mm (± 2.4 mm, 2 S.E.) for metamorph wood frogs and 38.5 mm (± 3.7 mm) for blue-spotted salamanders. Salamanders had a mean total length of 74.1 mm (± 5.7 mm). The mean 24-hour temperature high was 20°C (± 3.6°C) and the mean low was 15°C (± 4.2°C).

Metamorph wood frogs did not exhibit substrate selection in habitat trials without illumination (X^2 = 0.82, p>0.2, Table 1). Because we did not find selection, we only compared frogs in illuminated trials to a 1:1 substrate preference ratio, and did not find leaf litter selection when deciduous litter was illuminated (X^2 = 0.22, p>0.2, Table 1). When coniferous litter was illuminated, we found slightly more frogs selected coniferous litter (60% of frogs), but the change was not significant (X^2 = 1.48, 0.1<p<0.2, Table 1).

Metamorph blue-spotted salamanders strongly selected deciduous litter over coniferous litter (X^2 = 24.4, p<0.001, Table 1), with 81% of salamanders found in deciduous litter. Thus, we compared the illuminated trials to the observed ratio in habitat trials (37:5, deciduous:coniferous). The selection for deciduous litter remained when it was illuminated, with 72% of salamanders choosing deciduous litter (X^2 = 10.5, p<0.001, Table 1). The majority's choice shifted when coniferous litter was illuminated, with 55% of salamanders choosing coniferous litter in those trials (X^2 = 70.8, p<0.001, Table 1).

When compared to an expected 1:1 ratio, salamanders chose deciduous litter significantly more when it was illuminated (X^2 = 8.40, p<0.001, Table 1), but did not show a significant choice between coniferous and deciduous litter when coniferous litter was illuminated (X^2 = 0.40, p>0.200, Table 1).

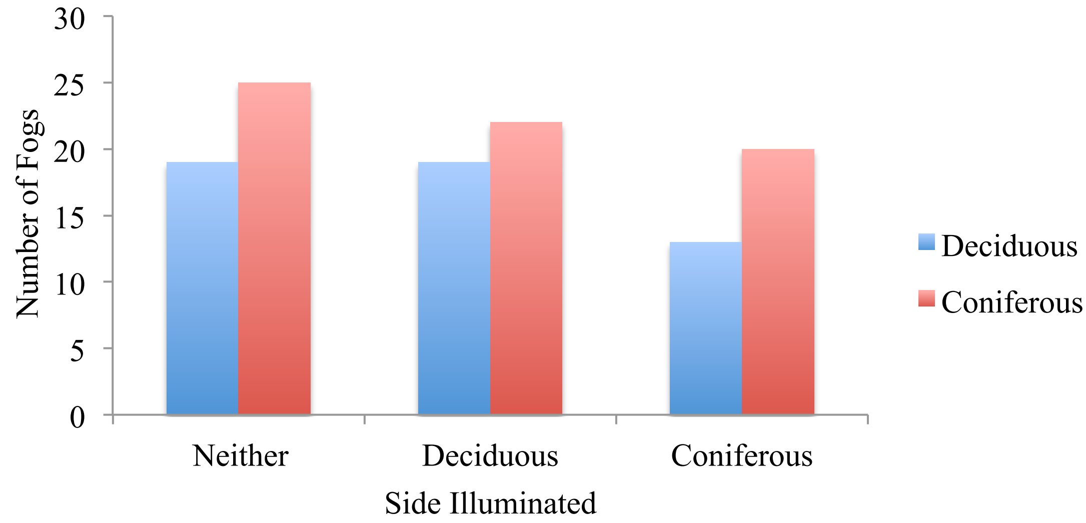

Figure 2. Total number of metamorph wood frogs found on either deciduous or coniferous sides of the mesocosms when neither side was illuminated by artificial light, when deciduous litter was illuminated, and when coniferous litter was illuminated.

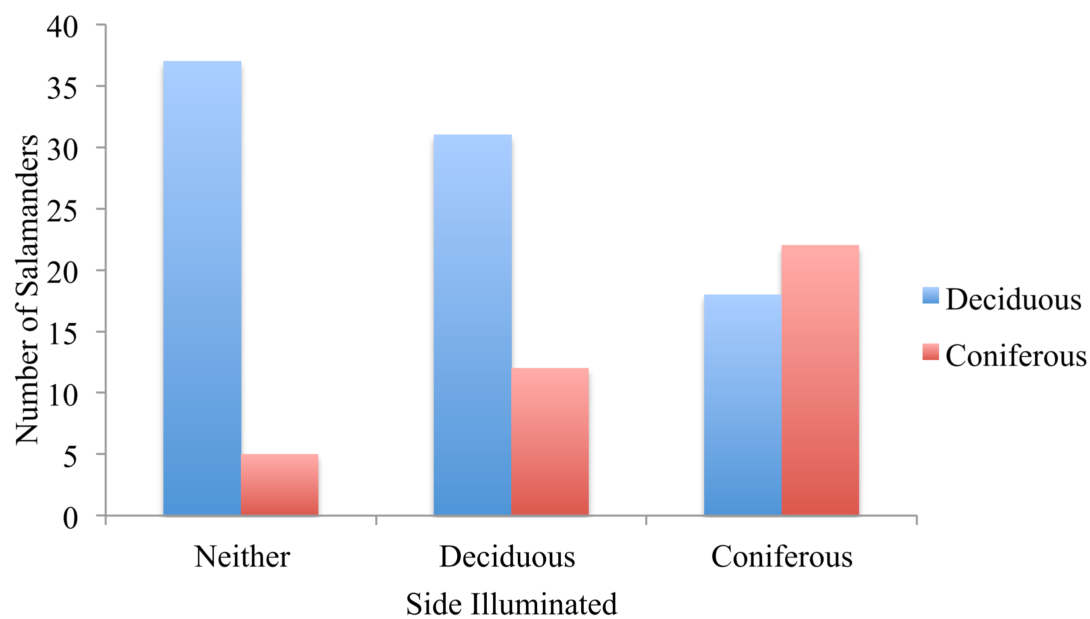

Figure 3. Total number of metamorph blue spotted salamanders found on either deciduous or coniferous sides of the mesocosms when neither side was illuminated by artificial light, when deciduous litter was illuminated, and when coniferous litter was illuminated.

Table 1. Results from chi-square goodness of fit tests including sample sizes, chi-square values, p-values, and total numbers of frogs or salamanders found in deciduous or coniferous litter in dark habitat trials and trials where either deciduous or coniferous litter was illuminated. For chi-square analysis, expected values were calculated using a 1:1 ratio for frogs, while for salamanders, one set of chi-square values were calculated using an expected 1:1 ratio and another using the ratios observed in the habitat trial.

Frogs

		Side Chosen			
Side Illuminated	N	Deciduous	Coniferous	X^2 (1:1 Ratio)	p-Value
Neither	44	19	25	0.82	$p>0.200$
Deciduous	41	19	22	0.22	$p>0.200$
Coniferous	33	13	20	1.48	$0.100<p<0.200$

Salamanders

		Side Chosen					
Side Illuminated	N	Deciduous	Coniferous	X^2 (Habitat Ratio)	p-Value	X^2 (1:1 Ratio)	p-Value
Neither	42	37	5	24.4	$p<0.001$	-	-
Deciduous	43	31	12	10.5	$p<0.001$	8.40	$p<0.001$
Coniferous	40	18	22	70.8	$p<0.001$	0.40	$p>0.200$

Discussion

Wood Frogs

We did not observe a difference in leaf litter selection in metamorph wood frogs, possibly because we controlled for canopy cover and humidity by placing tanks in a relatively homogenous forest stand and covering the tanks with plastic tarps. Both juvenile and adult wood frogs tend to select closed canopy habitat with dense understory and moist soil after emergence, while adults have been shown to additionally select areas with complex ground structure, *Sphagnum* moss, and coarse woody debris (deMaynadier and Hunter 1999; Blomquist and Hunter 2010; Baldwin et al. 2006). However, wood frogs can tolerate dry soil in upland areas if there is ample leaf litter, moss, or coarse woody debris to maintain moisture (Redmer and Trauth 2005). Though the specific microhabitat requirements of metamorph wood frogs are unknown, they are believed to be similar to those of adults (Redmer and Trauth 2005). Constible et al. (2001) found that adult wood frog presence positively correlated with deciduous leaf litter in Alberta, but aside from this, most wood frog habitat studies do not specify leaf litter composition when determining selection factors. Moreover, wood frog leaf litter humidity requirements are unclear, as Rittenhouse and Semlitsch (2007) found wood frogs to choose microhabitats with lower humidity compared to paired random locations, while Baldwin et al. (2006) found them to select more humid microclimates. As leaf litter can dictate humidity on a microclimate scale, these conflicting results complicate determination of a leaf litter selection in wood frogs. It is possible that metamorph wood frogs do not have a leaf litter selection on a microhabitat scale. Patrick et al. (2008) did not find juvenile wood frogs to select habitat on a small scale (two to four m^2 in their field experiments), only on the order of hectares, which included differences in forest stand treatments.

Frogs did not exhibit substrate selection when either leaf litter type was illuminated, but we did see a weak shift in choice ratios towards coniferous litter when it was illuminated. However, our illuminated coniferous trials also had the smallest sample size due to frogs escaping the mesocosms, which gave us lower statistical power to detect a change in selection ratio. Anecdotally, we also observed frogs sitting directly beneath the flashlight beam when we conducted morning counts, suggesting that some wood frogs may opportunistically feed in the light, filling a “night-light niche” as described by Gerber (1978). Alternatively, metamorph wood frogs may only respond to ultraviolet light, which is not emitted by the LED bulbs used in our illuminated trials. Connolly et al. (2011) found wood frog tadpoles to avoid sunlight after 15 minutes of exposure, which is beneficial in avoiding UV-B radiation that has been shown to be harmful to other species in the genus (Belden et al. 2003; Weyrauch and Grubb 2006).

Blue-Spotted Salamanders

Metamorph blue-spotted salamanders strongly selected deciduous litter in the dark habitat trials, likely due to deciduous leaves' higher moisture level than coniferous needles (Lee-Yaw et al. 2015). Ryan and Calhoun (2014) found post-breeding adult blue-spotted salamanders to select microhabitats with lower duff temperature, higher soil moisture, and deeper leaf litter than paired random locations. Deciduous litter provides the shade and high humidity required by ambystomatid salamanders. Though research on juvenile habitat selection is sparse, their higher surface area to volume ratio places recently metamorphosed salamanders at a higher risk of desiccation than adults, which requires them to seek out moist microhabitats. Deciduous and coniferous litters alter soil chemistry differently through their decomposition, which likely affects invertebrate communities available to salamanders (Kuiters and Sarink 1986; Friberg 1997; Raich and Tufekcioglu 2000; Woodcock et al. 2003). However, it is also possible that metamorph salamanders do not consider structure when selecting substrate: Ousterhout et al. (2014) found that juvenile spotted salamanders (*Ambystoma maculatum*) and small-mouth salamanders (*Ambystoma texanum*) selected grass substrate over leaf litter when both were in pulverized form. They hypothesized that this selection was driven by attraction to the high moisture content of grass substrate, and that these juvenile salamanders may be selecting microhabitat using moisture cues rather than visual cues, because they are entering a novel habitat when they leave their natal pools, with no prior knowledge of differences in leaf litter type. Thus, the salamanders in our study may have been attracted to deciduous litter simply because it held more moisture than the coniferous litter.

Salamanders showed strong selection for deciduous substrate when it was illuminated, and weaker selection for illuminated substrate when coniferous substrate was illuminated. These results contradict those from studies on other ambystomatid salamanders. Anderson (1972) found two subspecies of long-toed salamander (*A. macrodactylum croceum* and *A. m. sigillatum*) to be strongly photonegative as adults and found *A. m. croceum* to be weakly so as small larvae. Larvae became photopositive when they reached and SVL of 50 mm, then became photonegative again once they started to metamorphose. Schneider et al. (1991) found *A. tigrinum, A. punctatum,* and *A. maxicanum* to be photonegative as larvae, but they illuminated their trials to 286 lux, whereas Anderson (1972) illuminated his trials to only about 17 lux. It is assumed that these studies used incandescent bulbs in their studies, as the use of LED lighting did not become popular until the late 1990s. Our use of white LED lights may affect ambystomatid salamanders differently than incandescent yellow light, causing a difference in behavior. However, it is also difficult to compare our experiment to previous studies, as it was conducted in mesocosms that served as an intermediate between these laboratory experiments conducted in tanks and observation in a natural environment. By including leaf litter in our trials, salamanders were able to hide beneath the substrate and hide from the light.

The salamanders' attraction to illuminated substrate may be an attempt to opportunistically feed, but blue-spotted salamanders are fossorial as adults, feeding on invertebrates close to or under the earth such as beetles, spiders, centipedes, slugs, and earthworms (Lannoo 2005). Davies et al. (2012) found higher numbers of ground-dwelling invertebrates under streetlights in grassy substrates. In a forest setting, the common ground beetle (*Pterostichus melanarius*) is attracted to white light, but burrowing invertebrates such as earthworms and centipedes are known to avoid illumination (Ray 1986; Allema et al. 2012; Chipman et al. 2014). We did not monitor the behavior of invertebrates in the mesocosms, and more research is needed to understand how ground-dwelling invertebrates respond to artificial light in a forest setting.

Conclusion

LED bulbs are increasingly being used to light homes, businesses, roads, and sidewalks, as they are more energy-efficient and longer-lived than normal incandescent bulbs (Acuity Brands Annual Reports 2011-2014; Comstock 2014). Metamorph wood frog and blue-spotted salamanders do not appear to actively avoid LED light, which could increase their risk of predation in artificially illuminated areas as they migrate away from their natal pools. Artificial light has been shown to increase predator efficiency in hunting mice, and though mice have been shown to generally avoid illumination, our study species did not show avoidance (Clarke 1983; Farnworth 2016). Some amphibians have been shown to remain immobile in the presence of artificial light, which can further heighten predation risk (Mazerolle et al. 2005). Additionally, Rojas et al. (2014) found that avian predators attacked decoy frogs with more aposematic coloring less frequently in illuminated environments than more cryptically colored decoys. This could pose a threat to normally camouflaged wood frogs in artificial light conditions.

LED light also appears to draw blue-spotted salamanders out of deciduous leaf litter, which provides more moisture than coniferous litter and a possible difference in invertebrate communities. In Maine, the protective buffer around vernal pools does not account for light pollution. Up to 25% of this 250-foot radius can be developed, and if this development is illuminated with artificial light, migrating salamanders may travel toward the development rather than into the surrounding forest. This could create an ecological trap, traveling through exposed areas and possibly more susceptible to predation. Additionally, the 25% of the vernal pool buffer available for urbanization only accounts for structural development, allowing light pollution to cross into the protected 75% of the zone. Mazerolle et al. (2005) found amphibians had a high probability of remaining immobile when approached by vehicle headlights, both with and without the sound of the vehicle, making it possible that even the sudden illumination of substrate at night (caused by timed or motion-activated outdoor light fixtures) could disrupt amphibian movements from vernal pools. Further research is needed as to the effects of light pollution on adult wood frogs and blue-spotted salamanders, but if these results are consistent for all terrestrial life stages of these amphibians, there could be implications at the population level during spring migrations back to vernal pools to breed.

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Author Biography

Abbey Feuka was born in Portland, Maine and spent most of her childhood in Perry, Michigan. She will graduate with a B.S. in Wildlife Ecology and a minor in Earth Sciences. During her time at the University of Maine, she was a member of the Wildlife Society and the EWE-Maine Icelandics Sheep Club. Abbey has worked as a field technician on projects involving blue-spotted salamanders, wood frogs, and saltmarsh sparrows. In her freetime, she enjoys running, reading, hiking, gardening, and home brewing. Abbey plans to work as a field technician on various research projects before returning to graduate school to pursue an M.S. in Wildlife Ecology. Her research interests include wetland ecology, climate change, and urbanizaiton. Eventually, she hopes to work either as an environmental consultant, environmental educator, or as a full-time researcher.