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Abstract

Earthworms are an invasive species that are causing ecological damage to northern forest ecosystems. The disruption to soil nutrient cycling and litter decomposition can negatively impact organisms that live within the leaf litter, such as salamanders. To test this hypothesis, we sampled earthworms within three ravines at thirty-six sites using the mustard extraction method. We surveyed salamander populations on two dates in 2015 at each site using cover boards. We also collected data on slope aspect, altitude, soil moisture, leaf litter coverage, canopy cover, and coarse woody debris at each site to determine their effects on earthworm and salamander populations. Unexpectedly, our results show that total earthworm populations did not decrease salamander abundance. However, epigeic earthworms in north facing, low elevation sites did have a negative effect on salamanders. We also found that anecic earthworm species had a negative impact on leaf litter in south facing, low elevation sites. Using a GLIMMIX model, we found that epigeic earthworms had a negative effect on salamander populations, while anecic earthworms had a positive effect on salamander populations.

Introduction

Invasive European and Asian earthworm species have colonized much of North America, including northern temperate forest communities which have had no native earthworm populations. Unlike in disturbed agricultural soils, these exotic species have a negative effect on the soil and leaf litter structure of forests that they have invaded. Invasive earthworms have been shown to reduce leaf litter thickness by mixing it with mineral soil (Bohlen et al., 2004; Hale et al., 2005). This mixing of soil and litter changes preexisting soil dynamics and results in a decrease in the availability of carbon, nitrogen, and phosphorus (Bohlen et al., 2004; Fahey et al., 2013). The loss of nutrient availability can lead to decreased abundance and diversity of vegetation by allowing more aggressive plant species to dominate (Hopfensperger et al., 2011). These changes to the litter and soil can also affect animals that live in these habitats, such as other invertebrates and salamanders.

Salamanders are an important part of forest ecosystems, acting as top predators of litter and soil dwelling invertebrates (Wyman, 1998; Rooney et al., 2000), and as prey for birds, mammals, and snakes (Petranka 1998). They are highly abundant, making up more of the biomass of some forest communities than birds and mammals (Burton & Likens, 1975). However, they are very sensitive to environmental changes, making them susceptible to the changes that invasive earthworm species bring, and useful as bio-indicators for forest ecological integrity (Davic & Welsh, 2004). The reduction of litter from the forest floor removes habitats for both salamanders and the invertebrates they prey on, such as collembolans, which could decrease abundance and distributions of both.

Our goal was to determine the abundance and distribution of invasive earthworm species in the ravine forest ecosystem of Grand Valley State University, located along the Grand River in Ottawa County, Michigan. While there has been recent research on how earthworms impact vegetation and soil in hardwood forests (Bohlen et al., 2004; Fahey et al., 2013; Hale et al., 2005), there have been few studies looking at the effects of slope, altitude, and aspect on earthworm populations. We also wanted to determine the effects of earthworms on the abundance and distribution of salamanders and collembolans. We predicted that there would be more earthworms in cooler, moister areas, such as north facing slopes, or low altitude sites near creeks. We also predicted that earthworm populations would decrease salamander abundance. We used stratified random sampling of earthworms and salamanders, and assessed the physical environmental factors of both high and low elevations of north and south facing slopes. There was only one study investigating the effects of earthworms on salamander populations (Maerz et al. 2009), which did not take place in the Great Lakes region and did not include the effects of slope, altitude, and aspect on salamander distributions.

Materials and Methods

Study Sites – Our study took place in a mature, deciduous, mixed mesophytic forest of primarily oak-hickory and beach-maple in the ravines of Grand Valley State University, along the Grand River in Ottawa Co., MI. We used stratified random sampling to estimate earthworms and salamander populations within three east to west running ravines. We divided each of the three ravines into three equivalent strata, starting at the eastern end of the ravine and running west. Within each stratum, we randomly selected a point on both the north and south facing slopes of the ravine. We measured 5m from the top of the ravine at the chosen points and set up a 20m x 5m plot. Then we measured 5m from the bottom of the ravine at the chosen points and set up another 20m x 5m plot, resulting in a total of 36 plots.

Earthworm Sampling – Earthworms were sampled in late May, into early June. Each of the 36 20m x 5m plots were divided into two 10m x 5m sections. One side was randomly chosen to be sampled for earthworms, while the other side was used to sample salamanders. Within the 10m x 5m section, we chose two points, and placed a 35cm x 35xcm (1 square foot) metal frame at each point. We removed all leaf litter within the frame and searched for any residual earthworms within. We used a standard mustard extraction method (Gunn, 1992; McCay,

2013) to sample earthworms, in which 40g of mustard powder was dissolved in a gallon of water. We sampled all earthworms that came to the surface within fifteen minutes and put them into cups of 93% isopropyl alcohol. We preserved all earthworms in formalin for two days, identified them to species using the Great Lakes Worm Watch dichotomous key ("Key to exotic", n.d.), and put them into vials of isopropyl alcohol for storage ("Multiple plot studies", n.d.).

Salamander Sampling – Salamanders were sampled using eight 35cm x 35cm cover boards at each of the 36 sites. We divided each of the 10m x 5m sections into a 2x4 grid pattern, and placed a cover board near the center of each square of the grid. Leaf litter under each board was cleared so each board was flush with the soil. Cover boards were placed in May, and were checked once on the week of June 16, and again on the week of July 7. We lifted each cover board and counted all salamanders found underneath. We then identified them to species, measured their total length and their snout-vent length, and released them next to the cover board they were found under, allowing them to crawl back underneath.

Physical Factors – At each site, we measured soil moisture using a FIELDSCOUT TDR300 Soil Moisture Meter at eight points in a 2x4 grid pattern, then calculated mean ± sd. We determine leaf litter coverage and understory vegetation coverage by randomly selecting two areas within the earthworm side of the plot and estimating coverage of each type with a 1m x 1m quadrat, then we calculated mean ± sd for each type of coverage. We determined canopy cover by using a spherical densiometer to take four measurements at the cardinal directions in the center of each plot, then took the average ± standard deviation. We measured coarse woody debris (CWD) in each site by recording the number, length, and diameter of all pieces of CWD that were at least partially within a site (Gove & Van Deusen, 2011). We omitted sections of CWD that were elevated off of the ground, because they would not provide suitable cover for a salamander. The diameter and length were used to find the total volume of CWD in each site.

Statistical Analysis – We used Pearson Correlation Coefficients to find corresponding r and p values for the relationships between earthworms of each ecological group, salamanders, canopy cover, leaf litter coverage, understory vegetation, and soil moisture at different slope aspect and elevations. We also used a Generalized Linear Mixed Model (GLIMMIX) Type III test to determine if a given independent variable was a significant predictor of salamander abundance if all other variables being tested were held constant (Carruthers et al., 2008; Gibbs, 2008).

Results

We sampled 1183 invasive earthworms from eleven different species and 264 salamanders from two different species (Table 1). Earthworm abundance was higher in low elevation sites than in high elevation sites, but slope aspect had little or no effect on earthworm abundance (Table 2, Table 3). We found that in low elevation sites, earthworm abundance increased as understory vegetation increased, and in north facing sites, total earthworm abundance increased as understory vegetation increased (Table 5, Table 6). We found that in north facing, high elevation sites, as soil moisture increased, both endogeic earthworm abundance and salamander abundance increased (Table 7, Table 8). We also found a positive correlation between epigeic earthworm abundance and understory vegetation (Table 7). In north facing, low elevation sites, salamander abundance decreased as epigeic earthworm abundance increased (Table 7). In south facing, low elevation sites, salamander abundance increased as anecic earthworm abundance increased, and as anecic earthworm abundance increased, leaf litter coverage decreased (Table 7). We also found a positive correlation between total earthworm abundance and canopy cover (Table 7). We found that in south facing, high elevation slopes, leaf litter coverage decreased as epigeic earthworm abundance increased (Table 7).

From the GLIMMIX model we found that anecic earthworm abundance, soil moisture, and CWD all increased salamander abundance. However, epigeic earthworm abundance, canopy cover, and leaf litter coverage all decreased salamander abundance (Table 9). Slope aspect and elevation also had a significant impact on salamander abundance, with more salamanders being found in north facing, and high elevation sites (Table 9).

Discussion

We found that, contrary to our hypothesis, more salamanders were sampled in areas with a greater total earthworm population. We found that salamanders had a positive correlation with endogeic earthworms in north facing, high elevation sites, and with anecic earthworms in south facing, low elevation sites. These positive correlations may have been caused by salamanders being attracted to areas with higher earthworm populations to prey on them. Maerz et al. (2005) found that earthworms are commonly preyed upon by salamanders, especially in lowland areas. Anecic earthworms also had a strong negative correlation with leaf litter cover in south facing, low elevation sites, meaning that the close proximity to water and higher abundance of earthworms to prey upon may have compensated for any loss of leaf litter caused by the earthworms. Alternatively, the increase in salamanders sampled in those sites may have been caused by salamanders using the cover boards more often due to loss of leaf liter coverage. The results of the GLIMMIX model support this, as it showed that more salamanders were found in areas with lower leaf litter coverage. While we found these relationships between different earthworm ecological groups and salamander populations, we were unable to determine why these were only present at certain slope elevation and aspect combinations.

In forest ecosystems, salamanders depend on the leaf litter to provide moisture and protection. Maerz et al. (2009) examined earthworm total biomass and found that invasive earthworm species in forest ecosystems had a significant negative impact on leaf litter and many of the arthropods that salamanders prey upon, leading to lower salamander abundance. However, our findings that more salamanders were sampled in areas with lower leaf litter coverage does not support these conclusions. We did not investigate total earthworm biomass, but we did not find a significant relationship between total earthworm abundance and leaf litter. However we did find that anecic earthworm abundance and epigeic earthworm abundance did have a negative impact on leaf litter coverage in south facing, low elevation sites and south facing, high elevation sites respectively. But, as previously mentioned, this did not result in a decrease in salamander abundance.

We are still investigating other physical factors that could affect or be affected by earthworm and salamander distribution, such as soil pH and soil organic content. In addition, we are investigating the abundance of soil invertebrates that salamanders feed on within each of our sites, such as collembolans. Collembolans are a dominant group of arthropods that play an important role in the breakdown of plant detritus, making it more available to soil microbes, and stimulating bacteria and fungi colonies (Cassagne et al., 2006; Xiaodong et al., 2012). They are sensitive to changes in the soil, and their populations have been shown to decrease in the presence of invasive earthworms (Migge-Kleian, 2001; Burtis et al., 2014).

While sampling for salamanders, we also managed to find a rare invasive flatworm species, *Bipalium adventitium*, underneath one of our cover boards. *Bipalium* originates from southeast Asia, but was introduced to the United States within the last century (Hyman, 1943). *Bipalium* mainly preys upon earthworms, and has been found to be able to attack earthworms over 80 times its mass (Ducey & Noce 1998). Very few specimens have been collected in Michigan, one of which was found in the ravines of Grand Valley State University (Wheatley et al., 2014). If there is a breeding population of *Bipalium* in the ravines of Grand Valley, it could have a major effect on earthworm populations.

While our findings did not support our initial hypothesis, further study is required to better understand the effects that invasive earthworm species have on salamander populations. Increasing the sample size of earthworms and salamanders, or using a mark-release-recapture method of salamander sampling could provide more accurate data. Sampling at a more ideal time of the year for salamanders, such as earlier in the spring or later into fall, could also help increase sample size.

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Table 1. Earthworm and salamander species sampled in the forested ravines of Grand Valley State University, Ottawa Co., Michigan, 2015.

Earthworms Sampled	Salamanders Sampled
Allolobophora chlorotica	Blue spotted salamander (*Ambystoma laterale*)
Aporrectodia calignosa	Red back salamander (*Plethodon cinereus*)
Aporrectodia longa	
Aporrectodia trapezoides	
Aporrectodia tuberculata	
Aporrectodia rosea	
Dendrobaena octaedra	
Lumbricus rubellus	
Lumbricus terrestris	
Octolasion cyaneum	
Octolasion tyrtaeum	

Table 2. Comparison of earthworm populations, salamander populations, and physical data ($\bar{x}$±sd) between low and high elevations in the forested ravines of Grand Valley State University, Ottawa Co., Michigan, 2015.

	Low	High
Earthworms	36.00 ± 11.94 (n=18)	29.72 ± 11.13 (n=18)
Epigeic[3]	19.89 ± 7.10 (n=18)	17.06 ± 10.00 (n=18)
Endogeic[3]	14.39 ± 7.78 (n=18)	11.17 ± 6.81 (n=18)
Anecic[3]	1.50 ± 1.72 (n=18)	1.06 ± 1.26 (n=18)
Salamanders[1]	2.94 ± 2.82 (n=18)	3.78 ± 2.84 (n=18)
Salamanders[2]	3.06 ± 3.72 (n=18)	4.89 ± 3.69 (n=18)
Canopy %	93.24 ± 4.91 (n=24)	95.07 ± 2.24 (n=24)
Litter %	93.42 ± 4.66 (n=12)	78.75 ± 16.88 (n=12)
Vegetation %	38.19 ± 31.64 (n=12)	28.53 ± 25.72 (n=12)
Moisture %[1]	35.22 ± 10.82 (n=48)	26.95 ± 7.11 (n=48)
Moisture %[2]	35.95 ± 4.93 (n=48)	26.47 ± 6.41 (n=48)
CWD Volume (m^3)	1.69 ± 1.86 (n=18)	0.60 ± 0.62 (n=18)

[1] Data collected in June 2015. [2] Data collected in July 2015.

[3] Ecological groups of earthworms. Epigeic live in leaf litter, Endogeic live in mineral soil, Anecic live in deep burrows in mineral soil.

Table 3. Comparison of earthworm populations, salamander populations, and physical data ($\bar{x}$±sd) between north and south facing slopes in the forested ravines of Grand Valley State University, Ottawa Co., Michigan, 2015.

	North Facing	South Facing
Earthworms	32.22 ± 12.20 (n=18)	33.50 ± 11.73 (n=18)
Epigeic[3]	19.33 ± 8.09 (n=18)	17.61 ± 9.37 (n=18)
Endogeic[3]	11.39 ± 8.47 (n=18)	14.17 ± 6.05 (n=18)
Anecic[3]	1.28 ± 1.27 (n=18)	1.28 ± 1.74 (n=18)
Salamanders[1]	3.89 ± 3.12 (n=18)	2.83 ± 2.46 (n=18)
Salamanders[2]	4.61 ± 4.53 (n=18)	3.33 ± 2.81 (n=18)
Canopy %	94.56 ± 2.67 (n=24)	93.75 ± 4.84 (n=24)
Litter %	82.36 ± 17.21 (n=12)	89.81 ± 9.74 (n=12)
Vegetation %	37.83 ± 32.09 (n=12)	28.89 ± 25.31 (n=12)
Moisture %[1]	30.28 ± 9.85 (n=48)	31.90 ± 10.27 (n=48)
Moisture %[2]	31.14 ± 7.38 (n=48)	31.28 ± 7.66 (n=48)
CWD Volume (m^3)	1.35 ± 1.64 (n=18)	0.94 ± 1.30 (n=18)

[1] Data collected in June 2015. [2] Data collected in July 2015.

[3] Ecological groups of earthworms. Epigeic live in leaf litter, Endogeic live in mineral soil, Anecic live in deep burrows in mineral soil.

Table 4. Comparisons of earthworm populations, salamander populations, and physical data ($\bar{x}$±sd) between low and high elevations and north and south facing slopes in the forested ravines of Grand Valley State University, Ottawa Co., Michigan, 2015.

	North-Low	North-High	South-Low	South-High
Earthworms	34.33 ± 12.00 (n=9)	30.11 ± 12.74 (n=9)	37.67 ± 12.36 (n=9)	29.33 ± 10.02 (n=9)
Epigeic[3]	19.44 ± 3.28 (n=9)	19.22 ± 7.53 (n=9)	20.33 ± 9.80 (n=9)	14.89 ± 8.59 (n=9)
Endogeic[3]	13.56 ± 9.22 (n=9)	9.22 ± 7.53 (n=9)	15.22 ± 6.48 (n=9)	13.11 ± 5.78 (n=9)
Anecic[3]	1.11 ± 1.27 (n=9)	1.44 ± 1.33 (n=9)	1.89 ± 2.09 (n=9)	0.67 ± 1.12 (n=9)
Salamanders[1]	3.78 ± 3.03 (n=9)	4.00 ± 3.39 (n=9)	2.11 ± 2.47 (n=9)	3.56 ± 2.35 (n=9)
Salamanders[2]	3.56 ± 4.13 (n=9)	5.67 ± 4.90 (n=9)	2.55 ± 3.43 (n=9)	4.11 ± 1.90 (n=9)
Canopy %	94.56 ± 3.12 (n=12)	94.56 ± 2.33 (n=12)	91.92 ± 6.13 (n=12)	95.58 ± 2.16 (n=12)
Litter %	91.33 ± 4.99 (n=6)	73.39 ± 20.58 (n=6)	95.50 ± 3.38 (n=6)	84.11 ± 10.83 (n=6)
Vegetation %	36.39 ± 34.85 (n=6)	39.28 ± 31.12 (n=6)	40.00 ± 30.10 (n=6)	17.78 ± 13.31 (n=6)
Moisture %[1]	33.44 ± 11.61 (n=24)	27.11 ± 6.98 (n=24)	37.00 ± 10.34 (n=24)	26.80 ± 7.65 (n=24)
Moisture %[2]	35.35 ± 3.87 (n=24)	26.92 ± 7.79 (n=24)	36.56 ± 5.98 (n=24)	26.01 ± 5.12 (n=24)
CWD Volume (m^3)	1.86 ± 2.20 (n=9)	0.84 ± 0.56 (n=9)	1.52 ± 1.58 (n=9)	0.36 ± 0.61 (n=9)

[1] Data collected in June 2015. [2] Data collected in July 2015.

[3] Ecological groups of earthworms. Epigeic live in leaf litter, Endogeic live in mineral soil, Anecic live in deep burrows in mineral soil.

Table 5. Pearson correlation coefficients and p values (r(p)) of earthworm data with salamander and physical data between low and high elevations in the forested ravines of Grand Valley State University, Ottawa Co., Michigan, 2015. Significant relationships are in bold.

	Salamander[1]	Salamander[2]	Canopy	Litter	Vegetation	Moisture[1]	Moisture[2]
Earthworms Low	-.205(.4155)	-.282(.2565)	.212(.3981)	.173(.4914)	.498(.0355)	-.0597(.8139)	-.0541(.8311)
Earthworms High	.0370(.8841)	.0249(.9217)	-.178(.4808)	-.0212(.9334)	.324(.1898)	.0789(.7555)	-.00627(.9803)
Epigeic[3] Low	-.205(.4155)	-.347(.1580)	.385(.1149)	.341(.1662)	.0887(.7264)	.107(.6740)	-.351(.1531)
Epigeic[3] High	-.246(.3252	-.258(.3016)	.0549(.8289)	-.0891(.7251)	.485(.0416)	-.0841(.7401)	-.315(.2031)
Endogeic[3] Low	-.160(.5259)	-.200(.4258)	-.0145(.9545)	.0164(.9486)	**.643(.0040)**	-.146(.5640)	.248(.3213)
Endogeic[3] High	.379(.1207)	.373(.1277)	-.304(.2202)	.0329(.8969)	-.228(.3635)	.263(.2920)	.375(.1250)
Anecic[3] Low	.273(.2739)	.381(.1188)	-.102(.6883)	-.269(.2801)	.155(.5390)	-.248(.3206)	-.0956(.7059)
Anecic[3] High	.283(.2545)	.279(.2608)	-.355(.1478)	.109(.6678)	.319(.1973)	-.219(.3811)	.475(.0464)

[1] Data collected in June 2015. [2] Data collected in July 2015.

[3] Ecological groups of earthworms. Epigeic live in leaf litter, Endogeic live in mineral soil, Anecic live in deep burrows in mineral soil.

Table 6. Pearson correlation coefficients and p values (r(p)) of earthworm data with salamander and physical data between North and South facing slopes in the forested ravines of Grand Valley State University, Ottawa Co., Michigan, 2015. Significant relationships are in bold.

	Salamander[1]	Salamander[2]	Canopy	Litter	Vegetation	Moisture[1]	Moisture[2]
Earthworms North	-.158(.5304)	-.253(.3113)	-.384(.1155)	.222(.3760)	**.610(.0072)**	-.137(.5870)	.242(.3326)
Earthworms South	-.0603(.8123)	-.0839(.7405)	.264(.2901)	.0241(.9245)	.270(.2786)	.344(.1627)	.0666(.7928)
Epigeic[3] North	-.422(.0808)	-.443(.0656)	.0603(.8121)	.220(.3797)	.527(.0247)	-.161(.5246)	-.276(.2669)
Epigeic[3] South	-.139(.5836)	-.243(.3312)	.218(.3860)	-.0618(.8076)	.0601(.8128)	.300(.2263)	-.0229(.9282)
Endogeic[3] North	.149(.5562)	.0226(.9291)	-.555(.0167)	.0839(.7405)	.369(.1309)	-.00678(.9787)	.581(.0115)
Endogeic[3] South	.00198(.9938)	.0866(.7327)	.185(.4620)	.105(.6774)	.310(.2099)	.205(.4150)	.120(.6342)
Anecic[3] North	.215(.3913)	.265(.2887)	-.385(.1149)	.0863(.7334)	-.00384(.9879)	-.201(.4244)	.226(.3681)
Anecic[3] South	.300(2262)	.365(.1367)	-.117(.6445)	.100(.6918)	.481(.0433)	-.119(.6379)	.235(.3481)

[1] Data collected in June 2015. [2] Data collected in July 2015.

[3] Ecological groups of earthworms. Epigeic live in leaf litter, Endogeic live in mineral soil, Anecic live in deep burrows in mineral soil.

Table 7. Pearson correlation coefficients and p values (r(p)) of earthworm data with salamander and physical data between low and high elevations and North and South facing slopes in the forested ravines of Grand Valley State University, Ottawa Co., Michigan, 2015. NL means North-Low, NH means North-High, SL means South-Low, SH means South-High. Significant relationships are in bold.

	Salamander[1]	Salamander[2]	Canopy	Litter	Vegetation	Moisture[1]	Moisture[2]
Earthworms NL	-.307(.4218)	-.643(.0618)	.586(.0972)	.172(.6580)	.639(.0638)	-.356(.3475)	.433(.2444)
Earthworms NH	-.0260(.9470)	.115(.7687)	-.157(.6867)	.176(.6506)	.623(.0731)	-.0058(.9882)	.0627(.8727)
Earthworms SL	-.0109(.9778)	.167(.6676)	**.704(.0344)**	.0568(.8846)	.338(.3742)	.207(.5929)	-.394(.2940)
Earthworms SH	.145(.7098)	-.297(.4369)	-.199(.6077)	-.459(.2131)	-.446(.2293)	.178(.6471)	-.148(.7047)
Epigeic[3] NL	-.0265(.9460)	**-.786(.0120)**	-.317(.4063)	.276(.4726)	.229(.5537)	-.147(.7052)	.475(.1960)
Epigeic[3] NH	-.583(.0996)	-.424(.2549)	.228(.5552)	.251(.5153)	**.751(.0197)**	-.283(.4609)	-.478(.1936)
Epigeic[3] SL	-.363(.3370)	-.248(.5203)	.551(.1243)	.524(.1473)	.0487(.9009)	.210(.5884)	-.559(.1178)
Epigeic[3] SH	.319(.4029)	-.0298(.9394)	-.0482(.9019)	**-.690(.0396)**	-.456(.2176)	.135(.7292)	-.0687(.8606)
Endogeic[3] NL	-.388(.3015)	-.577(.1035)	-.596(.0903)	.134(.7312)	**.779(.0133)**	-.368(.3300)	.412(.2699)
Endogeic[3] NH	**.773(.0145)**	**.785(.0122)**	-.544(.1302)	-.154(.6918)	-.128(.7437)	.433(.2440)	**.713(.0311)**
Endogeic[3] SL	.311(.4160)	.477(.1937)	.465(.2075)	-.402(.2830)	.423(.2565)	.149(.7020)	.112(.7745)
Endogeic[3] SH	-.235(.5423)	-.514(.1571)	-.206(.5947)	.136(.7278)	-.102(.7939)	.112(.7743)	-.169(.6634)
Anecic[3] NL	-.0253(.9486)	.106(.7859)	-.443(.2320)	-.00657(.9866)	-.265(.4902)	-.307(.4219)	-.00569(.9884)
Anecic[3] NH	.415(.2671)	.351(.3546)	-.331(.3848)	.271(.4809)	.262(.4963)	.0382(.9223)	.589(.0955)
Anecic[3] SL	**.705(.0340)**	**.707(.0331)**	.0846(.8287)	**-.903(.0009)**	.447(.2273)	-.318(.4038)	-.178(.6466)
Anecic[3] SH	.0317(.9355)	-.0981(.8018)	-.272(.4797)	.179(.6451)	.112(.7743)	-.546(.1287)	.285(.4565)

[1] Data collected in June 2015. [2] Data collected in July 2015.
[3] Ecological groups of earthworms. Epigeic live in leaf litter, Endogeic live in mineral soil, Anecic live in deep burrows in mineral soil.

Table 8. Pearson correlation coefficients and p values (r(p)) of salamander and physical data between low and high elevations and North and South facing slopes in the forested ravines of Grand Valley State University, Ottawa Co., Michigan, 2015. NL means North-Low, NH means North-High, SL means South-Low, SH means South-High. Significant relationships are in bold.

	Canopy	Litter	Vegetation	Moisture[1]	Moisture[2]	CWD
Salamander[1] North-Low	.365(.3347)	.208(.5917)	-.307(.4212)	.253(.5105)	-	.526(.1458)
Salamander[1] North-High	-.494(.1765)	-.258(.5027)	-.313(.4127)	.328(.3889)	-	-.0913(.8152)
Salamander[1] South-Low	.328(.3882)	-.591(.0940)	-.0252(.9487)	.101(.7968)	-	-.407(.2767)
Salamander[1] South-High	-.0902(.8175)	.115(.7681)	-.515(.1562)	.0843(.8293)	-	.479(.1918)
Salamander[2] North-Low	-.102(.7937)	-.271(.4807)	-.121(.7561)	-	-.601(.0867)	.313(.4125)
Salamander[2] North-High	-.625(.0720)	-.320(.4016)	-.173(.6560)	-	**.816(.0074)**	-.0342(.9304)
Salamander[2] South-Low	.347(.3603)	-.506(.0940)	.145(.7094)	-	-.114(.7706)	-.418(.2633)
Salamander[2] South-High	.401(.2852)	.130(.7390)	.357(.3459)	-	-.516(.1548)	.661(.0525)

[1] Data collected in June 2015. [2] Data collected in July 2015.

Table 9. GLIMMIX Model Type III test of variables, given that all other tested variables are held constant, and accounting for aspect and elevation, to determine significant predictors of salamander abundance in the forested ravines of Grand Valley State University, Ottawa Co., Michigan, 2015. Significant relationships are in bold.

Variable	P value	Ecological Result
Aspect/Elevation	**.0340**	More salamanders found in north facing, and high elevation areas.
Epigeic Earthworms	**.0002**	Less salamanders found in areas with more epigeic earthworms.
Endogeic Earthworms	.2341	More salamanders found in areas with more endogeic earthworms.
Anecic Earthworms	**<.0001**	More salamanders found in areas with more anecic earthworms.
Canopy Cover	**.0095**	Less salamanders found in areas with more canopy coverage.
Leaf Litter	**.0076**	Less salamanders found in areas with high leaf litter coverage.
Understory Vegetation	.2910	Less salamanders found in areas with more understory vegetation.
Soil Moisture	**.0473**	More salamanders found in areas with higher soil moisture.
CWD Volume	**.0339**	More salamanders found in areas with more CWD.