Earthworm Species Composition and Distribution in the Upper Peninsula of Michigan

BIO 569: Practicum in Field Biology

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ABSTRACT

Ecosystems previously devoid of earthworms are now facing invasion by exotic species. Glaciers were thought to have eliminated earthworms from North America near the border of Canada. A survey was conducted around three different lakes and a forested site on the UNDERC property in Gogebic Co., Michigan to determine earthworm species composition and distribution. Three genera were found: *Aporrectodea*, *Dendrobaena*, and *Lumbricus*. The effect of abiotic factors including pH, moisture, nitrate, phosphate, and organic matter content in soil and leaf litter on earthworm abundance was studied. Analyses found that all abiotic factors except for pH, which showed a positive relationship to earthworm abundance, were not significantly correlated to earthworm distribution.

INTRODUCTION

Earthworm (Oligochaeta) colonies display a patchy distribution and may be composed of a variety of species. Their patches tend to be 20-40 m in diameter and are not synchronized with the population dynamics of other patches (Parmelee et al. 1998) but found in clumped spatial arrangements, with varied vertical and horizontal distributions (Doube and Brown 1998).

Research has shown that earthworm species composition and distribution is dependent upon the properties of the soil, including soil moisture, texture, depth, pH, and organic matter content (Curry 2004). However, local earthworm distribution can also significantly affect soil structure, varies from species to species.

A recent study on earthworm distribution in a forest system in southwestern Quebec, Canada showed a positive correlation between earthworm populations and soil moisture content (Whalen 2004). Soil texture may have an indirect influence on earthworm distribution through its effect on moisture relationships. Sandy soils tend to be inhospitable to worms, because they are prone to drought. Additionally, earthworms from temperate climates prefer soils within a pH range of 5.0-7.4 (Curry 2004).

Of the nearly 8,000 species found worldwide, 147 earthworm species are located in North America, north of Mexico (Hendrix and Bohlen 2002, Reynolds 1995). Among the earthworm species currently found in North America, 45 (31%) are nonnative (Reynolds 1995). Human activity has distributed nonnative, or exotic, worm species around the world (Hendrix and Bohlen 2002).

Earthworms may be classified in three ecological categories according to their vertical spatial arrangement: epegeic, endogeic, or anecic (Hendrix and Bohlen 2002). *Dendrobaena octaedra*, the most abundant earthworm species in the Ottawa National Forest, and *Lumbricus rubellus,* are both epigeic species, living and feeding in surface soil and plant litter. *Lumbricus terrestris* is anecic, feeding on surface litter, but dwelling in soil 2.5 m (8 ft) deep (University of California Sustainable Agriculture Research and Education Program 2002). *Eisenia rosia* and *Apporectodea tuberculata* are both endogeic species that live and feed in the soil mineral layer.

The most important aspect of earthworm ecology is their feeding activity. Earthworms gain nutrition from the soil or leaf litter they ingest, extracting the organic matter, which includes root and leaf litter debris, and grinding it in their gizzard (Curry 1998). The waste they expel forms structures called casts. Their feeding and cast-forming characteristics significantly affect soil structure significantly (Edwards and Shiptalo 1998). As a result of their feeding and burrowing activity, earthworms (particularly endogeic and anecic worms) thoroughly mix organic and mineral components of the soil (Edwards and Shiptalo 1998). Such activity can reduce forest floor thickness, which is considered to be a key component of the inherent stability of many forest ecosystems (Bohlen et al. 2004, Hale et al. 2005). Earthworm burrows affect the porosity (permeability to fluids) of soil. The extent to which soil porosity is affected depends largely on the number of earthworms in the soil, their spatial distribution, and their size. Increased soil porosity reduces soil erosion and may increase percolation through the soil profile. A recent study determined that earthworms alter carbon:nitrogen ratios, phosphorus fractions, and the distribution and function of fine roots and microbes (Doube and Brown 1998). While these effects may be beneficial to agricultural systems, they may be harmful to forest ecosystems over long periods of time if the forest is composed of plant species which have evolved or succeeded in the absence of earthworms (Bohlen et al. 2002, Hendrix and Bohlen 2002).

Native earthworm species may have been eliminated in most parts of Canada and the northern USA by Pleistocene glaciations (James 2004). Recolonization of these areas by native species has been very slow because their rates of expansion are quite low. For example, *Lumbricus terrestris* colonies spread 3-5 m per year (University of California Sustainable Agriculture Research and Education Program 2002). Because few native species would have inhabited these areas during the time of European settlement (Hendrix and Bohlen 2002) earthworms would have become established along lakes and streams where live bait has been released from fishing activity. Floods are also known to carry viable cocoons and live earthworms, thus they may be found in riparian zones and stream bottoms. The horticultural trade is another way worms have been spread (Kalisz and Wood 1995).

Few studies have been done at UNDERC on soil fauna, and to date, no earthworm studies have been done on UNDERC property. Surveys of the Ottawa National Forest (ONF), land surrounding UNDERC property, have found earthworms in over 70% of the forest and have revealed 5 exotic species: *Lumbricus terrestris*, *Lumbricus rubellus*, *Aporrectodea tuberculata*, *Eisenia rosia*, and *Dendrobaena octaedra* (S. Dunlap, personal communication).

Study Sites

I conducted surveys around three lakes and a forested area on the UNDERC property to determine earthworm distribution and abiotic associations. The surveys were done on Tenderfoot, Plum, and Bay lakes, as each lake has a different management profile. Tenderfoot and Plum are used for fishing; however, whereas Tenderfoot is open to the public, Plum is restricted to the clergy that visit the property. Bay, closed to the public in the 1930s when the UNDERC property was willed to Notre Dame, is now limited for use by UNDERC residents. Since 1991, only the visiting clergy have been allowed to use live bait (including earthworms) at Plum (G.E Belovsky, personal communication).

The selected control contained a mixture of hardwoods and was located inland. Bay, Plum, and Tenderfoot were surrounded by stands of mixed hardwoods and conifers.

METHODS

A 50-m transect was placed perpendicular from the edge of the lake at each cardinal direction (N, S, E, W). A GPS unit was used to determine the exact location closest to the exact cardinal point at each lake for transect placement. Each transect had 2 plots, one at point between 5-10 m from the shoreline and one at 50 m. The control site had two transects running parallel to each other (North-South) in a forested area. Each control transects had three plots: one at 0 m, 10 m, and 50 m. Sampling plots were defined within a square metal quadrat (0.093 m^2), that were excavated to a depth of approximately 15 cm. Leaf litter was collected within the cross-section of a PVC pipe (0.0082 m^2) and soil samples were taken at each plot. Soil moisture content was measured at each plot using a Lincoln soil moisture meter.

Earthworm sampling

Earthworms were obtained by chemical and physical extraction methods. A 1% solution of mustard seed powder in lake water was poured in the bottom of each quadrat sampled to extract anecic worms to the surface. Surface-dwelling and endogeic worms were gathered by hand sorting and sieving. Once collected, they were preserved in 70% ethanol. All worms (except for *D. octaedra*, keyed to species) were keyed to genus and measured (Dindal 1990). Species specific ash-free dry mass regressions (AFDMR) from Hale et al. (2004) were used to determine earthworm biomass.

Soil Chemistry

Soil and leaf litter samples were frozen for two weeks before they were processed, then were placed in a drying oven for 48 hrs. Portions of soil and litter samples were used to measure AFDM to determine organic matter content. Samples of soil and leaf litter were weighed, burned at 500°C for 2.5 hrs, and weighed again. The difference in mass was recorded as the AFDM.

A 10:1 slurry of soil and deionized water was made, and the liquid was filtered and used to determine pH, and nutrient content. A digital meter (Fischer AR15) was used to measure pH. HACH single parameter test kits were used estimate nitrate and phosphate levels. The samples used for nitrate testing were compared to 1-50 mg/L standards of potassium nitrate. Samples used to test phosphate content were compared to 0.5-25 mg/L standards of potassium phosphate pyrosulfate. Phosphate concentrations > 5 mg/L could not be detected, because phosphate standards above 5 mg/L were indistinguishable.

Statistics

Statistics were performed in SYSTAT 11. Descriptive statistics were performed on data collected from all locations. Student *t*-tests determined any significant distance-from-shore trends for biomass and worm numbers, while an one-way ANOVA was used to compare worm biomass among sites. Linear regression analyses examined worm biomass and abiotic factors. Species-specific regressions vs. abiotic factors were also completed.

RESULTS

Three genera were found on the UNDERC property: *Lumbricus*, *Aporrectodea*, and *Dendrobaena*. Average worm biomass varied between worms at locations near the shoreline and locations 50 m away (Figure 1). There was marginally higher worm biomass at 50 m than 0 m at Bay Lake ($p = 0.102$, $df = 6$, $t = -1.928$) and at Tenderfoot Lake ($p = 0.112$, $df = 6$, $t = 1.861$). Neither Plum ($p = 0.395$) nor the forest site ($p = 0.41$) showed significant differences in worm biomass (Table 1). ANOVA analysis (Bonferonni post hoc) found no significant differences in worm biomass between lakes and the forest site ($p = 0.657$, $df = 3$, F-ratio = 0.544).

All soil pH measured in this study ranged between pH 4.03-6.46 (Appendix 1). Worm biomass showed a positive relationship ($p = 0.018$, $R^2 = 0.184$, $df = 1$) to soil pH (Figure 2). There was a significant relationship between biomass and the number of worms ($p < 0.001$, $R^2 = 0.604$, $df = 1$). Linear regression analyses found neither AFDM litter ($p = 0.307$ nor AFDM soil ($p = 0.127$) to have significant relationships to biomass (Table 1). Linear regression analysis found no significant relationship between organic matter content of leaf litter and *D. octaedra* biomass ($p = 0.175$, $R^2 = 0.283$, $df = 1$, Figure 4). Nitrate and phosphate analyses were inconclusive. Most of the liquid samples fell within a concentration range that was undetectable, and could not be used in statistical analysis (Appendix 1).

DISCUSSION

As expected, earthworm population distribution was patchy. Bay supported more earthworms away from the shoreline than near it. Tenderfoot, on the other hand supported a higher abundance of earthworms near the water. Plum had a relatively equal proportion of worms near and away from the shore. The forest site displayed a difference in worm numbers at various distances, displaying a patchy distribution as earthworms are known to have (Parmelee et al. 1998). Also as expected, most of the genera (*Lumbricus*, *Aporrectodea*, and *Dendrobaena*) found in the ONF were found on the UNDERC property as well, suggesting these two properties share similar earthworm-viable soil characteristics, and perhaps, similar human impact pressures (fishing) that would promote earthworm invasion.

Other studies have found significant abiotic-factor:worm correlations (Curry 2004), but this study revealed only a relationship to pH. All soil pH measured in this study fell within the preference range of earthworms (5-7). The lack of significant relationships found between earthworms and other abiotic factors in this study may be a real artifact, or may be attributed to methodology: The moisture meter and nutrient test kits were not sensitive enough to accurately distinguish the abiotic measurements between lakes.

UNDERC property has a unique history of earthworm invasion compared to other places in the Great Lakes region, because it is environmentally protected and has rules against using live bait. [While fishing with live bait still occurs on a few UNDERC lakes, it is not as common as with lakes open to the public.]

Invasion may be comparatively slow to the outside environment and may not occur in any obvious pattern. From this study, it is difficult to determine how far beyond the selected lakes and forest earthworms have penetrated and whether they have significantly reduced the forest floor. AFDM litter measurements gave no solid indication of the effect of earthworms on leaf litter. In contrast, recent research by Hale et al. (2005) has shown that earthworm invasion of hardwood forests across Minnesota and the Great Lakes region has occurred rapidly, in many cases forming discrete transition zones where forest litter thickness diminishes greatly in as little as 75 m from areas that have litter layers up to 10 cm thick.

While *D. octaedra* is abundant on the ONF, it did not appear to be as abundant around the selected lakes and in the forest site in this study; thus, regression analysis did not show a significant effect on forest floor litter, its sole food source (personal observation).

In this study, replication was spread out rather than concentrated on one or two areas in order to determine differences among lakes. Indeed, earthworm biomass varied from lake to lake. More replication may yield a better understanding of the apparent trends, and direct comparisons between locations on UNDERC property with completely public areas could also be instructive.

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TABLES

Table 1. . ***t*-test comparisions of earthworm biomass at different distances at each location.**

***t*-test**	**p-value**	**df**	**t-value**
distance*avg. biomass Bay	0.102	6	-1.928
distance*avg. biomass Plum	0.395	6	0.916
distance*avg. biomass Tenderfoot	0.112	6	1.861
distance*avg. biomass Forest	**0.41**	**2**	**-1.035**

Table 2. **Linear Regression, earthworm biomass vs. different factors; significant differences are bolded.**

Linear Regression	**p-value**	**R^2**	**df**
pH/biomass	**0.018**	**0.184**	1
moisture/biomass	0.688	0.006	1
AFDM litter/biomass	0.307	0.037	1
AFDM soil/biomass	0.127	0.084	1
AFDM litter/*Dendrobaena* biomass	0.175	0.283	1
biomass/number worms	**< 0.001**	**0.604**	**1**

FIGURES

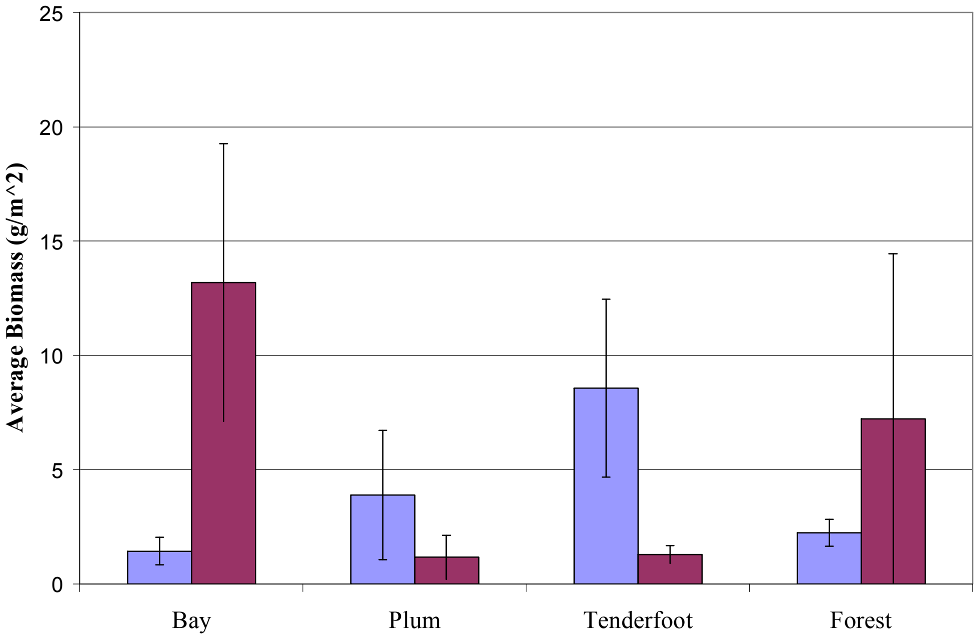

Figure 1. Average biomasses of worms near the shoreline (0 m = light blue) and at 50 m (dark) away from the shoreline at each lake. Overlapping error bars indicate insignificant differences. Bay ($p = 0.102$) and Tenderfoot ($p = 0.112$) show large differences in biomass near and away from the lake.

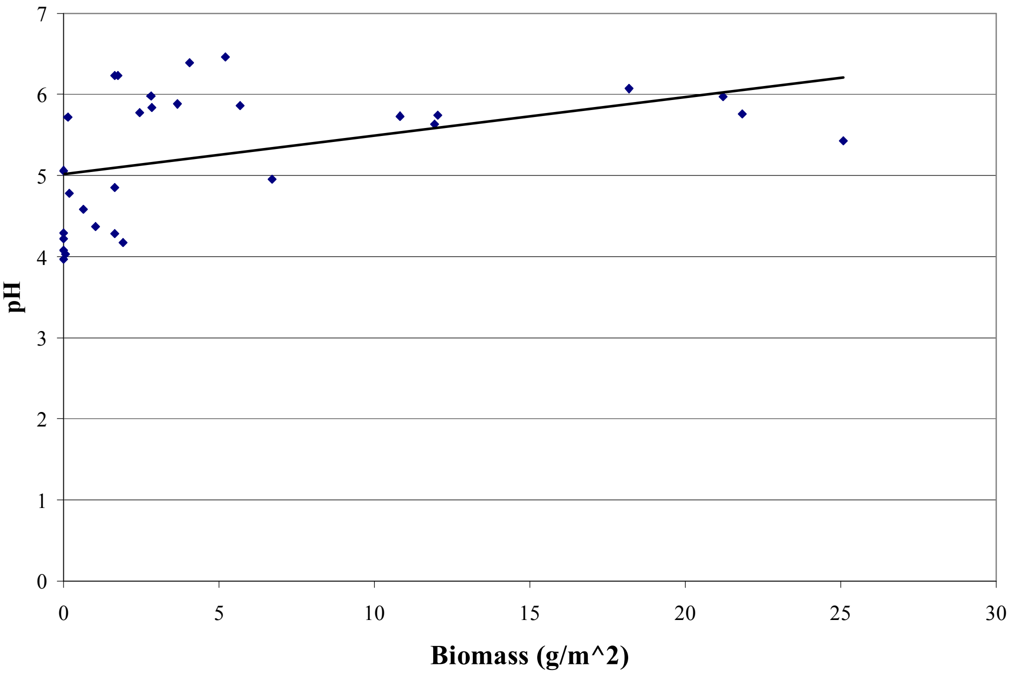

Fig. 2. Correlation between biomass and pH ($p = 0.018$, $R^2 = 0.184$, df = 1). Thirty samples are represented (Appendix 1).

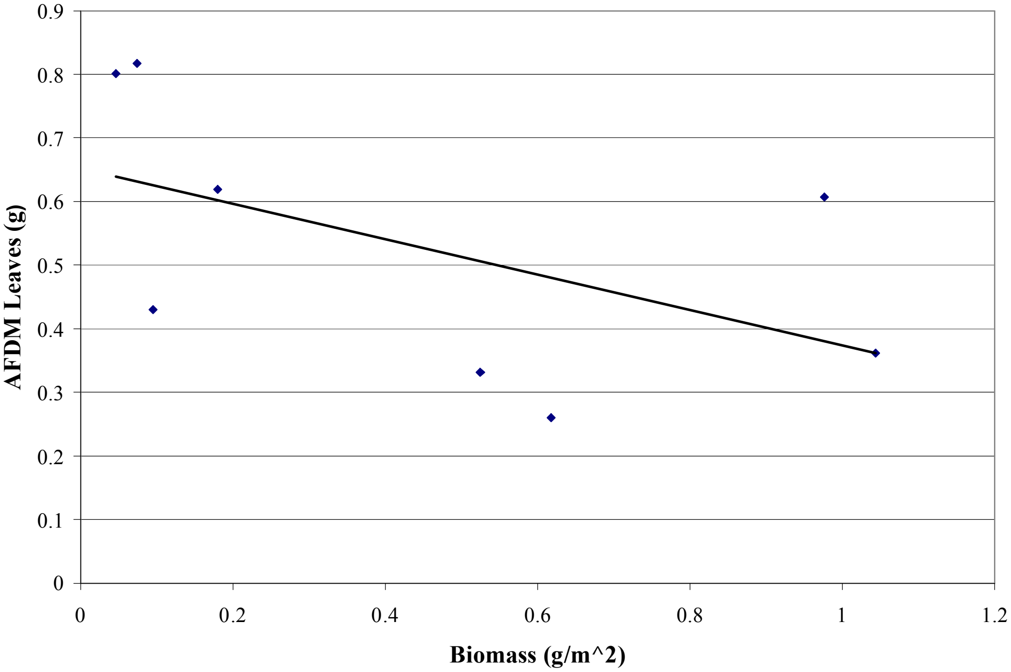

Figure 3. A correlation between *D. octaedra* biomass and AFDM of leaf litter ($p = 0.175$, $R^2 = 0.283$). Eight samples are represented.

APPENDIX 1. BN0 = Bay North near water; BN50 = Bay North away from water; BS = Bay South; BE = Bay East.

Sample	Worm #	Biomass	Phosphate (mg/L)	Nitrate (mg/L)	pH	AFDM Leaf (g)	AFDM Soil (g)	Moisture
BE0	9	2.80912789	<0.5	<1	5.98	0.969	0.221	1
BE50	8	21.829926	<0.5	<1	5.76	0.724	0.28	4.5
BN0	2	1.90960415	>5	2	4.17	0.639	2.026	6
BN50	5	5.67478506	<0.5	<1	5.86	0.841	0.317	5
BS0	1	1.02876796	2	1	4.37	0.324	1.595	6.5
BS50	1	0.18023621	0.75	1	4.78	0.619	0.638	5
BW0	0	0	<0.5	1	4.22	0.507	1.229	1
BW50	28	25.0868806	0.5	<1	5.43	0.861	1.142	5.5
FN0	2	1.65032157	2	1	4.85	0.332	1.021	5.5
FN10	6	6.70717	<0.5	<1	4.95	0.611	0.384	2
FN50	4	2.44577977	<0.5	<1	5.77	0.362	0.433	3
FS0	9	2.83468179	<0.5	<1	5.84	0.222	0.201	1
FS10	34	21.2069138	<0.5	<1	5.97	1.229	0.339	4
FS50	27	12.0289317	<0.5	<1	5.74	0.69	0.132	2
PE0	0	0	0.5	3	4.08	0.862	1.052	4.5
PE50	1	0.00017143	3	2	3.97	0.817	1.648	8
PN0	27	11.9379974	<0.5	1	5.63	1.059	0.106	7.5
PN50	5	4.04701578	0.5	<1	6.39	0.43	0.143	3
PS0	0	0	1	2	4.29	0.692	1.764	2
PS50	4	0.63728595	>5	2	4.58	0.801	0.793	2.5
PW0	14	3.65596644	<0.5	1	5.88	0.681	0.497	3
PW50	0	0	<0.5	1	5.06	0.853	0.432	2
T10	1	0.05574284	>5	3	4.03	0.924	4.724	2
T150	3	1.64047804	>5	2	4.28	0.26	1.762	9
T20	22	10.8146657	<0.5	1	5.73	0.837	1.997	3.75
T250	2	0.13045515	0.75	1	5.72	0.607	1.732	10
T30	28	5.19978691	<0.5	<1	6.46	2.305	0.299	7.5
T350	6	1.75288957	<0.5	<1	6.23	1.492	0.197	6
T40	48	18.195651	<0.5	<1	6.07	0.872	0.485	6.5
T450	8	1.6477415	<0.5	<1	6.23	1.147	ND	4