Migration Dynamics of Invasive Earthworms in Varied Soil Moisture Conditions at UNDERC

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Abstract

As an invasive species in the Great Lake region, earthworms significantly alter the structure and function of northern temperate forest ecosystems, particularly the sugar maple (Acer saccharum) dominated forest at the University of Notre Dame Environmental Research Center (UNDERC) in the Upper Peninsula of Michigan (Hale et al. 2005). Because earthworm invasion is heavily mediated by humans, particularly through release of excess fishing bait in riparian areas (Keller et al 2007), the study sought to examine the effects of varied soil moisture on earthworm migration rates. Earthworms of species *Aporrectodea* spp., *Lumbricus rubellus*, *Lumbricus terrestris* were tagged using Visible Implant Elastomer technology and released at plots of varying soil moisture. Of the 1350 earthworms released, 487 were recaptured using an electro-shocking method 10 and 21 days following release. Observation and subsequent statistical analysis determined that there was no difference in migration rates among species or at varying soil moistures. However, a significant negative relationship was found between soil moisture and recapture rates. Accordingly, earthworms released in higher moisture areas remained in the release plot at lower rates. Further studies are necessary to determine whether this phenomenon is caused by increased migration or decreased earthworm survivorship.

Introduction

Earthworms, particularly genera *Aporrectodea*, *Dendrobaena*, and *Lumbricus*, are not native to the soils of the northern temperate forests of North America. After earthworms were eliminated during the last glaciation period, 11,000 to 14,000 years ago, the forests of the northern United States and Canada developed earthworm-free for thousands of years (James 1995). European earthworm species were introduced to the Great Lakes region in the mid-1800s with European settlement of the area (Great Lakes Worm Watch) and are now considered to be invasive to the region, notably to the forests of UNDERC.

A study by Hale et al. (2005) suggests that earthworm invasion and the subsequent effects have the potential to dramatically alter both the structure and function of northern temperate forest ecosystems. Regions where earthworm invasions have occurred display reduced plant species richness (Holdsworth et al. 2007) and altered nutrient cycling and availability (Bohlen et al. 2004). Additionally, earthworms have been shown to reduce or eliminate the organic horizon of the forest floor. Reduction in the forest floor is particularly significant because it facilitates soil erosion and impedes forest regeneration following disturbance (Bohlen et al. 2004).

Not only do earthworms have the potential to drastically alter forest systems, but studies predict that a substantial portion of northern hardwood forests will be altered by the effects of earthworms in the coming decades (Hale 2008). Due to the potentially broad effects earthworm invasion may have on northern temperate forest ecosystems, it is essential to understand earthworm populations. Specifically, a greater understanding of earthworm dispersal dynamics would be useful to determine forest regions most susceptible to earthworm invasion. A study conducted by Hale et al. (2005) found that earthworms migrate only five to ten meters per year; however, humans have long been known to play an integral role in the spread of earthworm populations. Diversity and abundance of earthworm species have been directly linked to human impact in forest areas (Holdsworth et al. 2007b).

Worms used as fishing bait are an especially prevalent vector of earthworm dispersal and invasion. Often, excess bait is dumped in moist soils surrounding fishing and boating docks (Keller et al 2007). In this study, I examined the effects of human behavior, particularly the dumping of earthworm bait in moist soils, on earthworm dispersal. Specifically, I sought to determine if earthworm dispersal rates in riparian habitats, such as those near docks, was significantly different from dispersal rates in upland environments. Earthworm species under consideration were the *Aporrectodea* spp., *Lumbricus rubellus*, *Lumbricus terrestris.* Several studies have investigated the effects of changes soil moisture on earthworm populations. Parmelee et al. (1990) found a 75% population reduction when there is a 60% reduction in soil moisture, indicating that earthworms survive best, and perhaps disperse most, in soils of higher moisture. Thus, it can be hypothesized that earthworms will display the greatest dispersal rates in riparian habitats. If this is the case, fishermen magnify the damage of earthworm release by dumping excess bait in riparian soils.

Methods

This study was conducted in a sugar maple (Acer saccharum) dominated forest at the University of Notre Dame Environmental Research Center (UNDERC) in the Upper Peninsula of Michigan. Earthworms were released at ten plots. Plots were confined to a single hectare, chosen for proximity of upland and lowland environments that were expected to vary little beyond soil moisture differences. Five “high moisture” soil plots and five “low moisture” soil plots randomly selected. Plots were placed at least 10 meters apart in order to maintain independence of each plot replicate. In plot selection, soil moisture was measured using a soil moisture probe. Following worm release and recapture, soil moisture samples were taken at each plot using a soil corer. Samples were weighed, dried, and reweighed to determine the moisture content.

Migration of three worm species was examined. To model a scenario of excess bait dumping, high volumes of worms were released at each plot. For each plot, 100 *Aporrectodea* spp., 20 *L. rubellus,* and 15 *L. terrestris* were released. *Aporrectodea* used for the study were collected on the UNDERC property using the electroshocking technique (Bohlen et al. 1997). *Lumbricus* species were both collected in the field and purchased at a fishing bait store.

Prior to release at plots, visible implant elastomer (VIE) technology was used to tag worms. It is formulated for marking invertebrates and small aquatic animals and injected into the organism. VIE is found to remain stable and visible in worms for up to 12 months. Furthermore, VIE has been found to have no significant effect on earthworm survival, growth or reproduction (Butt and Lowe 2007). We injected earthworms with a single tag placed on posterior segments. We monitored the injected earthworms for 24 hours to ensure survival and viability after tagging.

Ten days following release, worms were recaptured at 4 upland and 4 lowland plots. The other two plots were sampled after 21 days. Three 1.5 meter transects, 120˚ apart, were made at each plot and worms were collected from each using the electroshocking method. Two half-meter electrodes were placed parallel to each other and one half meter apart to shock a quarter meter plots of soil. Electrodes were made of wooden planks with quarter meter metal probes attached. The probes were implanted into the soil to transmit current to the soil area of interest. On each transect, electroshockers were run for 20 minutes, rotated 90˚, and run another 20 minutes in the rotated position. Worm species, distance from release point, and presence or absence of tag were recorded for all worms collected on the transect line. Earthworm dispersal rate was calculated based on distance traveled in the time since release. Three weeks (21 days) following release, worms were recaptured at the one remaining upland and lowland plot.

Data collected was graphed and analyzed to determine differences in distance traveled and recapture rates across different soil treatments and across different species. Microsoft Excel and Systat 12 were used. Statistical tests implemented included Least Squares Linear Regression and One-way ANOVA tests.

Results

Overall, 1733 earthworms were collected in the eight plots sampled ten days after release with electro-shocking sampling. Of the 1733 earthworms collected, 375 were tagged *Aporrectodea*, 15 tagged *L. rubellus*, and 28 tagged *L. terrestris* (418 tagged overall).

For the three species of earthworms released, the median ($p=0.975$, $r^2=0.0002$) (Fig 1) and maximum distance traveled ($p=0.337$, $r^2=0.1316$) (Fig 2) was not related to the percent soil moisture. The median distance traveled was also no different between the three species released ($F_{2.20}=1.418$, $p=0.27$). Recapture counts of tagged earthworms of all species was found to have a negative relationship with soil moisture ($p=0.030$, $r^2=0.5719$) (Fig 3). However, there was no apparent relationship between soil moisture and the natural earthworm density, as indicated by the number of untagged earthworms collected ($p=.632$, $r^2=0.0644$) (Fig 4). Natural earthworm density, (collection counts of untagged earthworms), was significantly different among species ($F_{2.20}=3.466$, $p=0.000$). Natural *Aporrectodea spp*. density was significantly greater than *Lumbricus spp*. densities ($p=0.000$). Collection counts of tagged earthworms was also significantly different among species ($F_{2.20}=154.675$, $p=0.000$), specifically between *Aporrectodea spp*. and *L. rubellus* ($p=0.000$). Accordingly, there was a significant difference in recapture rates among species ($F_{2.20}=17.27$, $p=0.000$). The recapture rate of *Aporrectodea spp*. was significantly greater than that of either *L. Terrestris* (p-value=0.003) and *L. Rubellus* (p-value=0.000) but there was no significant difference in the recapture rates of the two *Lumbricus* species.

Recapture conducted on one upland plot and one lowland plot after 21 days yielded 424 earthworms. Of the 424 earthworms collected, 69 were tagged *Aporrectodea spp.*, 2 tagged *L. rubellus*, and 5 tagged *L. terrestris*, and 76 were tagged overall. The average distance traveled from release point was not greater in plots where earthworms were recaptured after 21 days (Fig 5); however, recapture rates were less than recapture rates after only 10 days (Fig 6).

Discussion

In the soils of UNDERC's deciduous hardwood forest, soil moisture was not shown to be a factor in earthworm migration rates. For all worm species examined (*Aporrectodea, L. terrestris, L. rubellus*) soil moisture did not have a significant effect on either median distance or maximum distance traveled from a release point. Thus, the null hypothesis that there is no difference in worm migration rates across varying soil moisture treatments cannot be rejected.

According to Hale et al. (2005), earthworms have been found to migrate only five to ten meters per year. Given this estimate, in the ten days of the sampling period, the maximum migration of a worm, would be less than 30 centimeters. Although some worms traveled greater than 30 centimeters during the ten day run of the study, the majority did not. Therefore, ten days may have been an insufficient amount of time to properly gauge migration rates and fine distinctions in migration rates among species.

Similarly, examination of species as a potential factor affecting earthworm migration rates in UNDERC soils showed that there was no significant difference between median distance traveled from release point among the different species investigated. We were unable to reject our null hypothesis, suggesting that migration rates are not different among *Aporrectodea, L. terrestris, L. rubellus* earthworms**.** As was the case with soil moisture, the lack of significant differences in migration among species can be attributed to the short period during which the experiment was run. Data collected on one upland plot and one lowland plot after 21 days did not show a noticeable increase in average distance traveled compared to plots where recapture was conducted after 10 days, further illustrating the minimal migration of earthworms in the given time frame of the study. Due to the relatively slow earthworm migration rates, ten days may not have been a sufficient amount of time to gauge small differences in migration rates among species.

Although soil moisture was not shown to play a role in migration alone, results suggest that moisture affect earthworm recapture rates. There was a clear negative relationship between soil moisture and recapture rates of tagged earthworms of all species investigated yet this relationship was not present, or was positive for untagged earthworms. The effect of soil moisture on recapture of tagged worms is significant enough that the null hypothesis can be rejected. Soil moisture may have a negative relationship recapture of tagged earthworms due to specific soil moisture preferences of earthworms. The greatest numbers of worms have been found to occur in soils of 12-35% moisture (Olsen 1928). Soil moisture in lowland plots was generally higher than this; thus decreased recapture rates as soil moisture increased suggests that soil moisture in lowland, high moisture plots was unfavorable. A laboratory study found that *L. rubellus* survive high moisture conditions with escape behavior (Zorn et al. 2007). Accordingly, high moisture plots may have had a “flood” effect on *L. rubellus* released, resulting in an escape from the high moisture area. If this were the case, *L. rubellus* worms released may have migrated away from the release plot altogether and therefore not present within 1.5 meters of the release point 10 days later. This postulation is supported by data collected for plots where recapture was conducted 21 days post release. No *L. rubellus* worms were recaptured 21 days following release, reinforcing the possibility that *L. rubellus* worms were no longer present on the plot.

However, this fails to explain the significantly decreased recapture rates of *Aporrectodea spp*. and *L. terrestris* worms. A second Zorn et al. (2004) study conducted on a floodplain in the Netherlands found that *Aporrectodea. spp* populations were not effected by flooding, and biomass of *L. terrestris* actually increased. Further, Zorn et al. (2004) found that *L. terrestris* are more likely to remain closer to the surface in flood conditions. Given this result, it would be more likely that the *L. terrestis* worms would be recaptured with electroshock sampling.

The findings of Zorn and others (2004) also fail to explain differences in recapture rates among varying soil moistures when collection counts of untagged worms are considered. Soil moisture was not shown to effect collection counts of untagged worms. Notably, soil moisture was not an effective predictor of *L. rubellus* abundance, as Zorn et al. (2007) suggests. Accordingly, worm abundance was not a product of soil moisture. This suggests that there was a difference in released tagged worms and untagged worms naturally present in lowland plots that allows the untagged worms to survive in higher moisture conditions. Tagged worms were collected from soil moistures similar to those of upland sites and possibly unconditioned for survival in higher moistures. Further studies could examine the survival rates of earthworms when placed soil moistures different from the soil moistures in which they actually occur. This would shed light on differences in collection rates of untagged but not tagged worms in varying soil moisture.

Along with varying soil moisture, species was also found to be a significant factor in determining recapture counts. This is not surprising; collection counts of untagged worms were also found to be significantly different because *Apporectodea* are more abundant in the soils of UNDERC forests (David Costello, pers. comm.). However, rate of recapture was also different among species, between *Aporrectodea* and each *Lumbricus* species. This may be the result of varying tolerance for different soil moisture conditions among species. *Aporrectodea* species population size is not significantly affected by changes in soil moisture, while *Lumbricus* species biomass is altered by changing soil moisture conditions (Zorn 2004).

The study showed that, regardless of species or soil moisture, earthworm migration occurs at very slow rates. However, the greatest cause of large scale earthworm invasion is human-mediated dispersal (Callaham et al. 2006). Results of the study illustrate no difference in earthworm migration rates in varied soil moisture; however, it was shown that fewer released earthworms remain moist soils after being released there. Wetter soils may decrease earthworm survivorship. This would suggest that the practice of bait dumping by fishermen in moist riparian soils near boat docks poses less risk to earthworm invasion. Conversely, earthworms may fail to remain in wetter soils because of the avoidance hypothesis postulated by Zorn and others (2007). If this were the case, moist soils may induce increased migration. Earthworm bait dumping in wetter areas would amplify the effects of earthworm release and invasion. Further studies examining earthworm survivorship in varied soil moisture would be useful; however, regardless of soil moisture and earthworm survivorship, earthworm release is never an advisable way to dispose of excess bait.

Figures

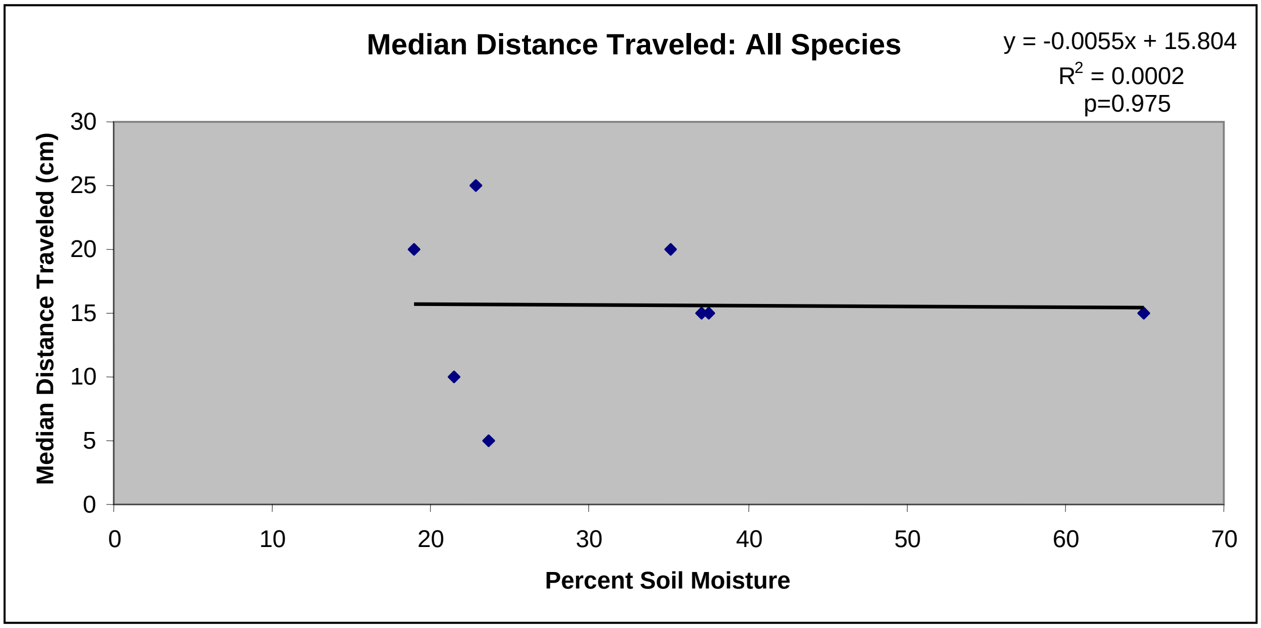


Figure 1: Median distance of earthworm travel from release point over a period of 10 days, as related to percent soil moisture.

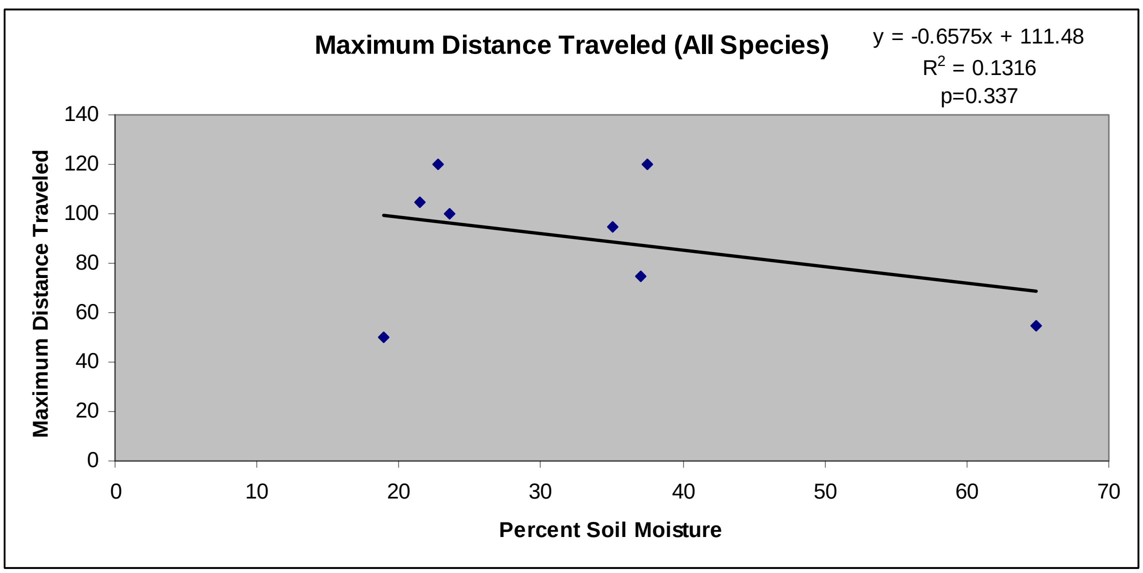


Figure 2: Maximum distance of earthworm travel from release point over a period of 10 days, as related to percent soil moisture. Each point represents a separate plot.

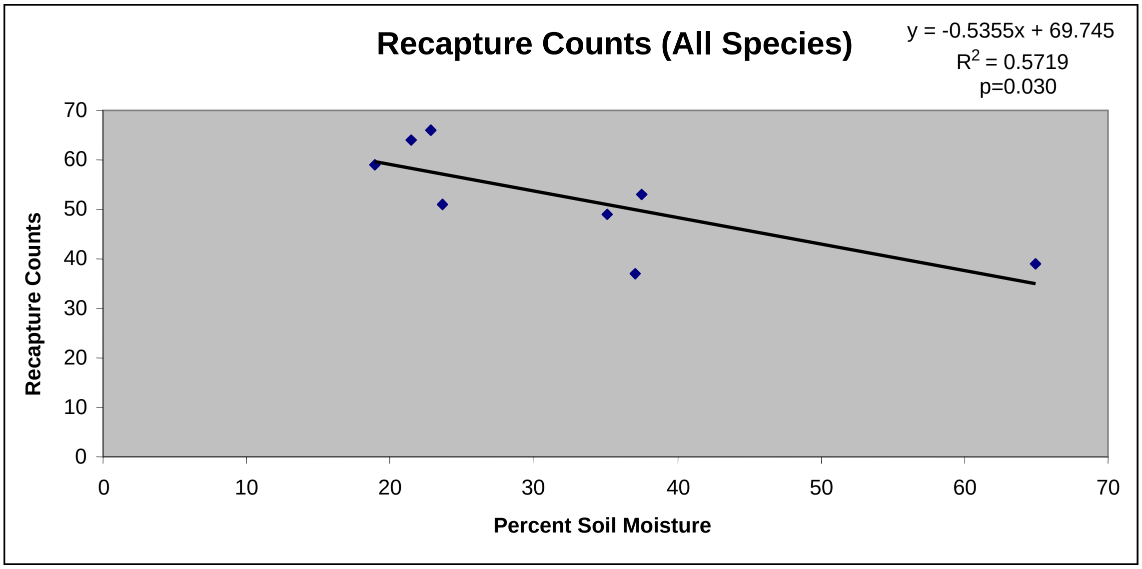


Figure 3: Recapture counts of tagged earthworms after 10 days.

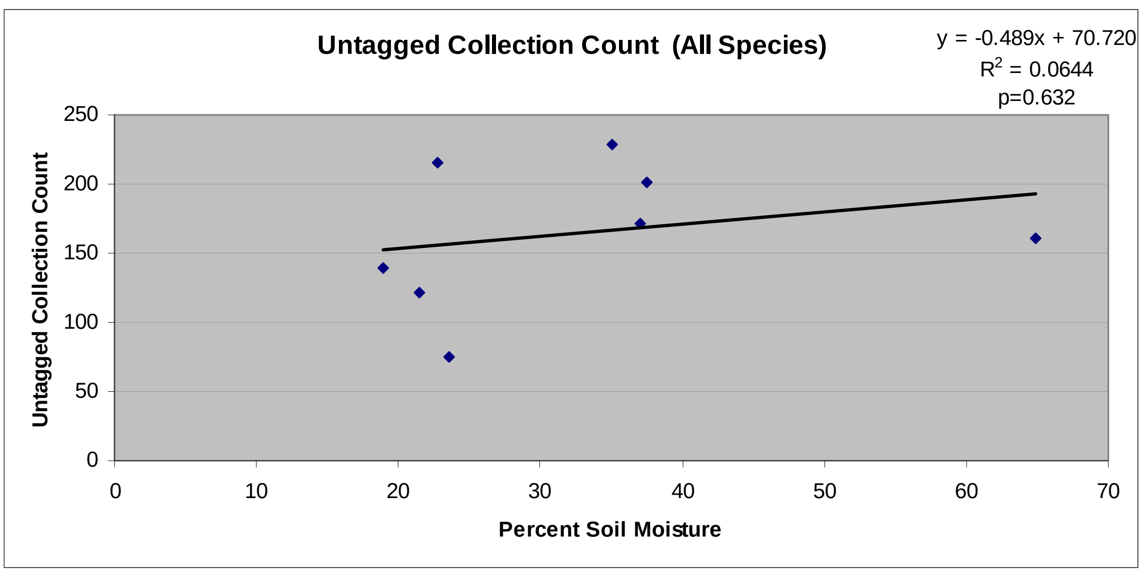


Figure 4: Collection counts of untagged earthworms after 10 days.

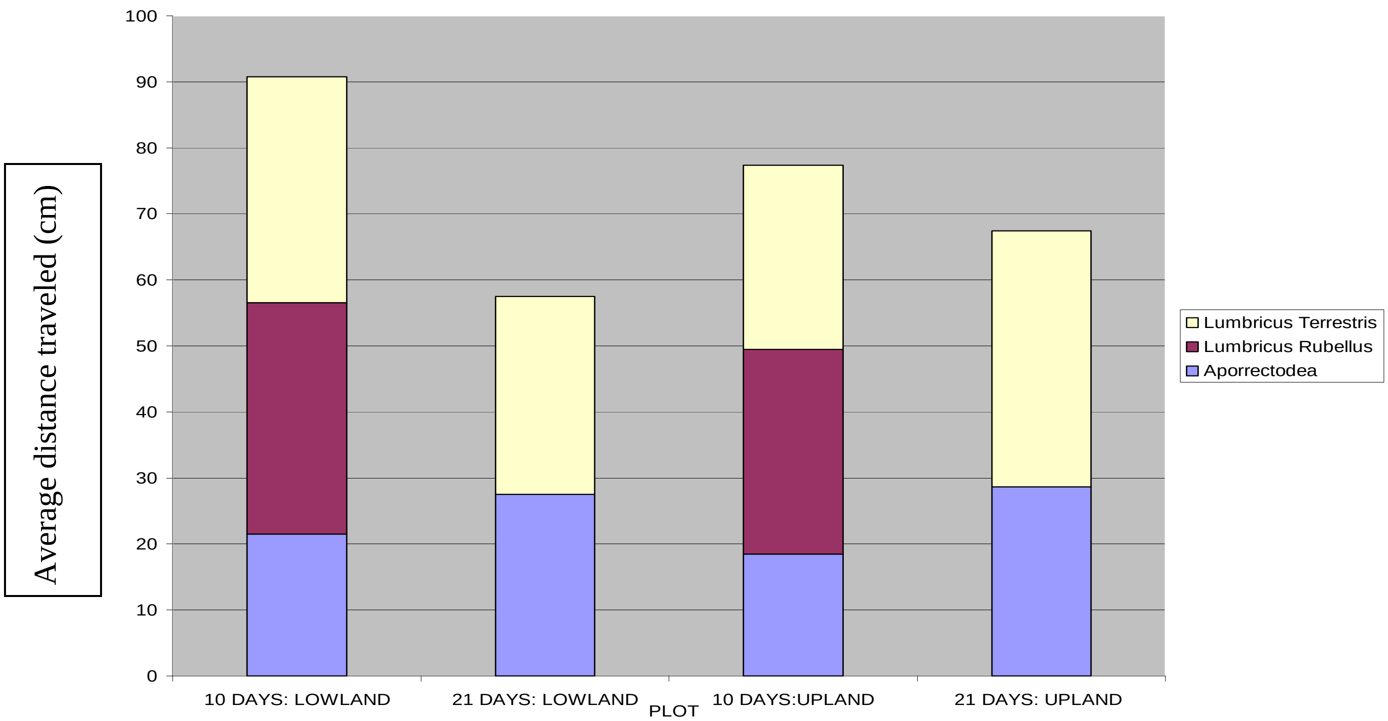
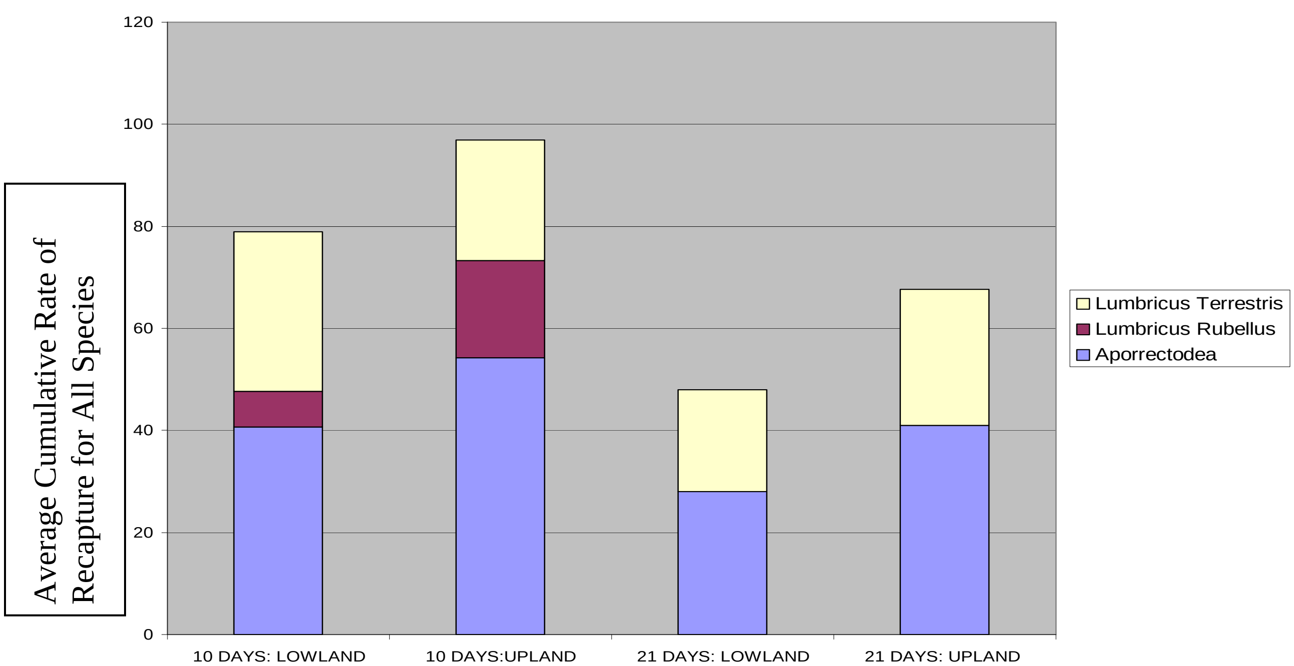


Figure 5: Cumulative average distance of earthworm recapture from release point at each plot after 10 and 21 days.



PLOT

Figure 6: Average percent of recapture at varying moisture and time since release. Recapture rates decrease after 21 days.

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