The Forest Floor: A study on the relationship among trees, leaf litter, and earthworms

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Abstract

The relationships among tree species, leaf litter, and detritivores are vital to the forest ecosystem dynamics. Trees of deciduous hardwood forests drop their leaves every autumn, greatly contributing to the overall leaf litter abundance. This leaf litter blankets the forest floor, creating a microhabitat that effects the floor community and soil composition. Decomposers such as earthworms within this system consume and process the leaf litter, in turn having a major effect on the soil nutrients and the litter composition. This continuous cycle of leaf litter development and putrefaction has a major influence on the composition of the entire forest community. The null hypothesis is that there is no relationship among trees, leaf litter, and earthworms within the forest. Leaf litter and earthworms were collected from the UNDERC (University of Notre Dame Research Center located adjacent to the Ottawa National Forest) deciduous hardwood forest systems. Those trees within the vicinity of the litter collection were measured for DBH (Diameter at Breast Height) and distance from the litter collection sight. Each tree was identified to species. Each leaf in the litter was also identified to species. The data was applied to the leaf litter prediction model developed by Ferrari and Sugita (1996), which illustrates the expected amount of leaf litter to drop from each tree. It was found that the sampled leaf litter matched the predicted model exceptionally well for yellow birch, and fairly well for sugar

maple trees. Both found a positive relationship. However, there was no parallel pattern for basswood. The total sampled litter demonstrated a negative relationship with the predicted model. Therefore, the null hypothesis was rejected for the yellow birch and sugar maple models, but failed to be rejected for basswood and total leaf litter models. It was also found that there was no significant relationship between the sampled leaf litter and the biomass of the collected earthworms. In conclusion, it is suggested that there is a relationship between the trees and the forest floor community, however further studies must be conducted to establish what this relationship is.

Introduction

Ecosystems depend on many species to maintain a continuous cycle of regeneration and sustainable life. The alteration of one aspect within this system can result in complete disruption. Fluctuations and changes within the system do occur, often eventually resulting in total ecosystem changes. Influences from immigration and emigration can attribute to these changes(McMillan 1969).

A temperate deciduous forest ecosystem is made up of a complex composition of various organisms and the relationships they have to one another. This particular ecosystem is remarkably abundant in tree species, and those organisms, which depend upon them for survival. Some of the least understood but most valuable interactions within the hardwood forest ecosystem occur on the forest floor. The forest floor is an active area for beneficial organism relationships (Rochow 1974). The composition of nutrients and organisms depend on the aboveground flora and the belowground fauna.

One group of organism, decomposers play an important role in the regeneration of the forest. The growth and germination of the forest flora is dependent upon nutrient-rich soils and an abundant amount of water. Decomposers of the forest floor depend upon an abundance of litter matter (fallen leaves, reproductive parts, twigs, logs, and other debris from the aboveground organisms) for survival. The continuous nutrient cycling within these relationships continue to promote life and growth in forests. It is here, in the composition of the forest floor that they are abundantly found. The organic matter consumed by these decomposers is produced by the large tree species, plus the small shrubby understory (Bohlen et al., 2004). The decomposition of organic matter is essential for the continuous nutrient cycling, and the survival of the ecosystem.

In most deciduous forests, leaf litter is a major part of the organic material found on the forest floor. This litter is important to the ecosystem in many ways; not only does it provide protection and insulation of flora roots but also provides food and protection for the various small fauna species that dwell within the forest. The decomposition relationship contributes to topsoil creation and retention. The community composition of the forest system is dependent upon the litter dynamics (Elliott *et.al.* 1993). Jonard and coworkers (2006) modeled leaf litter dispersal as a prediction of the physical and chemical characteristics of the forest floor. These characteristics are important in nutrient cycling and in plant population dynamics.

Tree species of the hardwood forest have a great influence on the composition of the leaf litter. In the autumn, the leaves of deciduous trees fall, contributing to the forest floor's litter. In addition to decomposition, precipitation and leaching of leaf litter contributes to the concentration of nutrients in the soil. Leaf litter not only affects the aboveground organisms, but also those systems and relationships that occur belowground. The relationship between the tree species and the detritivores species at the leaf litter level is key to the makeup of the ecosystem as a whole (Knutson 1997).

Earthworms are the primary decomposers in most temperate deciduous forests. Their role of eating leaf litter, transferring nutrients, and aerating the soil also affects the aboveground species. Earthworms are recognized by many as organisms that have an ecosystem-scale effect due to their decomposition of leaf litter and contribution to nutrient cycling (Hale et al., 2005). However, most studies on decomposers have concentrated on bacteria and fungi found inhabiting the leaf litter. Elliott (1993) describes he and his coworker's results on decomposers in terms of metabolic rates of bacteria and fungi in relation to litter abundance with no reference to earthworm contribution to decomposition.

The hardwood forests of the northern United States do not contain native earthworms; all earthworms found in this ecosystem are non-native species (Hendrix and Bohlen, 2002). Because the effects earthworms have on the composition and abundance of leaf litter on forest floors is significant, total ecosystem changes may be occurring with changes in earthworm abundance and diversity. The few studies that have been preformed (such as those conducted by E.R. Suarez, P.F. Hendrix, P.J. Bohlen, and C.M Hale) are a good basis for developing an understanding of the intricate relationship these organisms have with their surrounding environment. However, more studies must be conducted to adequately describe this delicate connection between earthworms (as decomposers), leaf litter, and arboreal species (Hendrix and Bohlen, 2002). The purpose of this study is to determine the relationships within a temperate deciduous forest ecosystem between the flora (with concentration on the tree species), leaf litter abundance and composition, soil composition, and earthworm densities. The null hypothesis is that there is no relationship among the aboveground processes (involving the diversity, abundance, and composition of trees), the leaf litter abundance, and the belowground processes (i.e. soil composition, and as well as the earthworm community).

Methods and Materials

This study is based at the University of Notre Dame Research Center (UNDERC) in the Upper Peninsula of Michigan, adjacent to the Ottawa National Forest. Most of the forested ecosystem area can be described as continuous deciduous hardwood forest.

Ten 50m x 50m plots were randomly selected from the UNDERC property. Using a grid of property, and only those sections lying in forested areas were selected for plots. Five subplots were selected at random for sampling. Each of these subplots were 961 square centimeters (31cm*31cm). The examination of the selected plots in each stand were tested for the identification of the fallen leaf and standing tree species, leaf litter abundance and composition, and soil structure. The trees (with a DBH less than 10cm) within a 17-meter radius from the subplot point were measured. The 17meter radius is consistent with the average radius where the majority of the leaf litter fall of individual trees observed by Ferrari (1996). Each tree within this area was identified to species, the distance from the subplot, and the Diameter at Breast Height (DBH) were measured.

The leaf litter from within the subplot (which had an area of 961-cm^2) was collected and each leaf was identified and a count for each species was taken. The mass (in grams) of the total leaves from each species was measured. Soil cores were taken from each subplot, and these cores were used to determine soil moisture, pH, and percent organic matter.

Earthworms from each subplot were extracted using a mustard concentration poured and soaked into the soil. The extraction solution used at each subplot consisted of 40g of ground yellow mustard powder in 3.8 liters water. The worms were collected within 20 minutes of administration of the mustard. This method was adopted from Gundale (2005). The earthworms were preserved with a 70% ethanol solution(Hale *et.al.* 2004). These earthworms were later identified to species and the total body length in millimeters was taken. Formulas for calculating the dry biomass of each earthworm, was adopted from Hale (2004).

For the aboveground model a formula calculating the expected leaf litter fall from each individual tree based on species, DBH, and the distance from the plot was adopted from Ferrari and Sugita (1996) and their studies in the Ottawa National Forest. The particular model adapted from Ferrari and Sugita (1996) with a few alterations will be implemented to illustrate the results of the study. Their study concentrated on the dominant tree species of the hardwood forest ecosystem.. Therefore their parameters are calculated for sugar maple, basswood, hemlock, and yellow birch. These parameters were applied to all the species in the leaf litter fall calculations where they were deemed to have the best fit. The studies conducted by Ferrari and Sugita (1996) were performed in the Sylvania Wilderness Area, which consists primarily of old-growth hemlock-hardwood habitat. This old-growth forest is within close proximity to the location of UNDERC. It was determined that leaf litter dispersal is dependent upon distance, species, and DBH of the neighboring trees. The model incorporates two functional patterns of leaf fall, one being the relationship between litter biomass and tree DBH, and the other the litter's distance from the base of the tree. The individual species parameters were based on calculated maximum likelihood estimates. The model is calculated under the assumption that leaf dispersal from an individual tree follows an exponential decline pattern with relation to distance. It was found that the distance hemlock leaves travel from the host tree is significantly shorter than those leaves of basswood, sugar maple, and yellow birch. Of the remaining three tree species basswood's leaf dispersal distance extends beyond those of the other two. Because the most dropped leaves are experienced in the fall months Ferrari and Sugita (1996) conducted their study between August and October, basing their calculated parameter on the fall foliage. The dry weight of each collected litter sample was used to ensure accuracy. Ferrari and Sugita (1996) suggest that incorporation of sampled leaf litter into such models establishes the prospect of an ecosystem-sized representation of dispersal patterns.

The data collected was graphed, and the proper statistical tests were implemented. Linear regression tests were used, both simple least square regression, and multiple stepwise regression. Software programs such as excel and Sysstat12 were used for data analysis.

Results

There was an abundant diversity of trees measured within the plots. In the respective order, the four most prominent families consist of Aceraceae, Pinaceae, Betulaceae, and Tiliaceae. All of the species found while sampling include: Paper Birch (*Betula papyrifera),* Quaking Aspen (*Populus tremuloides),* Big-tooth Aspen (*Populus grandeidentata),* Black cherry (*Prunus serotina),* White ash (*Fraxinus nigra),* Yellow birch (*Betula alleghaniensis),* Hop-hornbeam (*Ostrya virginiana),* Basswood *(Tilia americana),* Sugar maple (*Acer saccharum),* Red maple (*Acer rubrum),* Red pine (*Pinus resinosa),* Balsam fir (*Abies balsamea),* and White cedar (*Thuja occidentalis).* The dominant species of the sampled forest was sugar maple, which makes up 66.3% of the measured trees. The second most prominent deciduous tree species within the UNDERC hardwood forest stands is yellow birch (*Betula alleghaniensis*), it was 6.1% of the measured trees. Basswood (*Tilia americana*) makes up 4.2% of the forest community. The other species ranged between quaking aspen (*Populus tremuloides*) at 3.6% and Hop-hornbeam (*Ostrya virginiana*) at 0.2%.

An aboveground model was developed to examine the relationship between the tree species and the forest leaf litter. Linear regression tests were run on the calculated litter data. The dependence of the leaf litter mass on different species with the hardwood forest varied. A least squared regression demonstrated that yellow birch showed the most influence on the litter. The regression presented a p-value of 0.001 and an r^2 value of 0.927. Sugar maple, the dominant species in the community also demonstrated an influence on the leaf litter with a p-value of 0.082 and an r^2

value of 0.331. Finally, basswood, the third most prominent tree species demonstrated little to no influence on the total litter, with a p-value of 0.197 and an r^2 of 0.006.

The difference between the calculated predicted leaf litter mass and the sampled mass was found. Regression analysis was run to determine the influence the earthworm species had on the missing leaf litter. *Lumbricus spp.* had a p-value being 0.439 and the r^2 value of 0.012 in relation to the total litter difference. This being the best (in relation to the other species of worms) of p and r^2 values calculated for the total leaf litter mass. Sugar maple and yellow birch show similar results. The calculated sugar maple p-value is 0.622, and the r^2 value is 0.005. The yellow birch p-value is 0.152 and the r^2 value is 0.042. There was no significance found for basswood; however, it was found that the basswood was most affected by the presence of Aporrectodae species, the calculated p-value is 0.167 and the r^2 value is 0.039.

Discussion

In the hardwood forest of UNDERC the tree composition effects the leaf litter fall. The overwhelming domination of sugar maple in the area reduces the populations and survival of other species. However there are a few stands of other species, which have resisted this dominance, of which their effect on the leaf litter and forest floor composition is evident. The most prominent and dominant species in the area have the largest effect. Within the subplots tested sugar maple, yellow birch, balsam fir, and basswood were the most prominent species. However, balsam fir was not considered in this study because it is a coniferous tree. Conifers, unlike deciduous trees have a very small leaf surface area, and therefore do not contribute a significant amount to the leaf litter found on the forest floor. Due to their leaves' needle-like shape and leaf density the proximity from the tree the leaves fall is very close (Ferrari 1996). Among the three deciduous species there was a great amount of variation in not only the abundance of trees but also the extent of the effects each species had on the forest floor.

The regression analysis showed a distinct relationship between tree species and leaf litter mass and composition. The prediction model for leaf litter fall from yellow birch trees shows an overwhelming influence on the actual sampled yellow birch litter. The calculations demonstrate that the model can accurately predict litter on the forest floor. Because of the great influence it shows, the null hypothesis is rejected. There is a relationship between the forest floor and the individual trees. Yellow birch was the second most abundant tree sampled on property. This may be due to an observed pattern of yellow birch's exploitation of light. It was observed by Beaudet and Messier (1998) that newly established canopy gaps were filled with young yellow birch saplings. This advantage to early regeneration of developing yellow birch stands, may have a major influence on the leaf litter composition for that area.

Sugar maple also demonstrated a great influence on the leaf litter and the forest floor community. The pattern illustrated by the linear regression analysis depicts that a pattern is present. As the predicted leaf litter mass increases, so too does the mass of the sampled leaf litter. This trend establishes that the relationship between the forest floor and the sugar maple trees is significant enough to reject the null hypothesis. The high Sugar maple dominance at UNDERC has an influence on the leaf litter mass of the forest floor. The sample size for sugar maple was significantly larger than all other trees sampled, which aided in the accuracy of the prediction model.

Basswood, which covers up to 4.2% of the entire forest system, presents no significant influence on the forest floor. This limited contribution of basswood to the leaf litter was surprising. Although basswood only contributed a marginal amount to the composition of the forest tree stands, the regression analysis showed no pattern. However, the parameters developed by Ferrari (1996) were calculated based on autumn leaf fall. The sampled data for this collection was taken during the summer months. Most of the leaves collect in the leaf litter from basswood were reproductive leaves. They are significantly smaller than productive leaves of the basswood, which normally fall in the autumn months. Therefore, without this consideration the model parameters are inaccurate and the model faulty. This results in a failure to reject the null hypothesis.

The pattern presented by the linear regression displaying the accuracy of the total leaf litter mass was drastically different than those of yellow birch, sugar maple, and basswood. This is curious, because although the combination of sugar maple and yellow birch make up 76.6% of the forest's trees, the model pattern shows no resemblance. The slightly downward slope of the total leaf litter regression suggests that there is a negative relationship between the predicted model and the sampled litter mass. However, there is not a definite significance to the pattern, resulting in a failure of rejection of the null hypothesis. Although both sugar maple and yellow birch show a strong pattern and significance to a positive relationship, the total leaf litter does not. This suggests that the remaining tree species that makes up the other 23.4% of the forest each have a important influence on the forest floor constitution.

Trees, however, are not the only influential factors on leaf litter. Decomposers within the forest floor have a great effect on the abundance of leaf litter present (Curry *et.al.* 2007). At UNDERC the dominant detritivores that obtain their nutrients from the consumption of leaf litter are earthworms. It was found that earthworms, along with trees have an effect on the leaf litter at UNDERC. A belowground model was developed for the same subplots.

There is a key difference between the calculated predicted leaf litter mass and the sampled leaf litter mass. The subplots show a major lack in the amount of leaf litter expected to fall from the sampled trees. The "missing" leaf litter mass was analyzed with the belowground model. It was found that the Lumbricus genus demonstrates the most influence on the leaf litter abundance. Again, the analysis produced insignificant results and there was a failure to reject the null hypothesis. *Lumbricus spp.* also proved to be the most influential on the lack of both yellow birch and sugar maple leaf litter. These results were marginally significant and failure of rejecting the null hypothesis is again instituted. Basswood's missing leaf litter, however, was most affected by the *Aporrectodea spp.* The insignificance of the results fails to reject the null hypothesis.

Throughout the study there were a few sources of error. One of the most influential ones is the limitation of the use of the formula and parameters adopted by Ferrari (1996). Even though the study was conducted in the neighboring Ottawa

National Forest, the parameters were only provided for Sugar maple, Yellow birch, Basswood, and Hemlock species. The diversity of other species found in our study did not fit into these parameters. Also, those trees with a DBH less than ten centimeters were excluded, which left out many leaf-bearing trees. Many of the tree stands were very similar, and there was a lack of stand age diversity and species stand composition.

Future work on the activity of earthworms, leaf litter, and tree species is necessary to fully demonstrate their relationship. Studies such as this are crucial to illustrate the effects. Other studies should include parameters for all of the sampled tree species, a wider testing area, more sample sites, and diversity in the composition of the sample sites. Other things that should be taken into consideration in further studies might also include the physical features and characteristics of the sample plots. Such as the slope of the land, the mineral composition, and the annual climate of the area (including precipitation, wind, and temperature) should be taken into consideration.

Acknowledgements

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Very Important Results

Figures

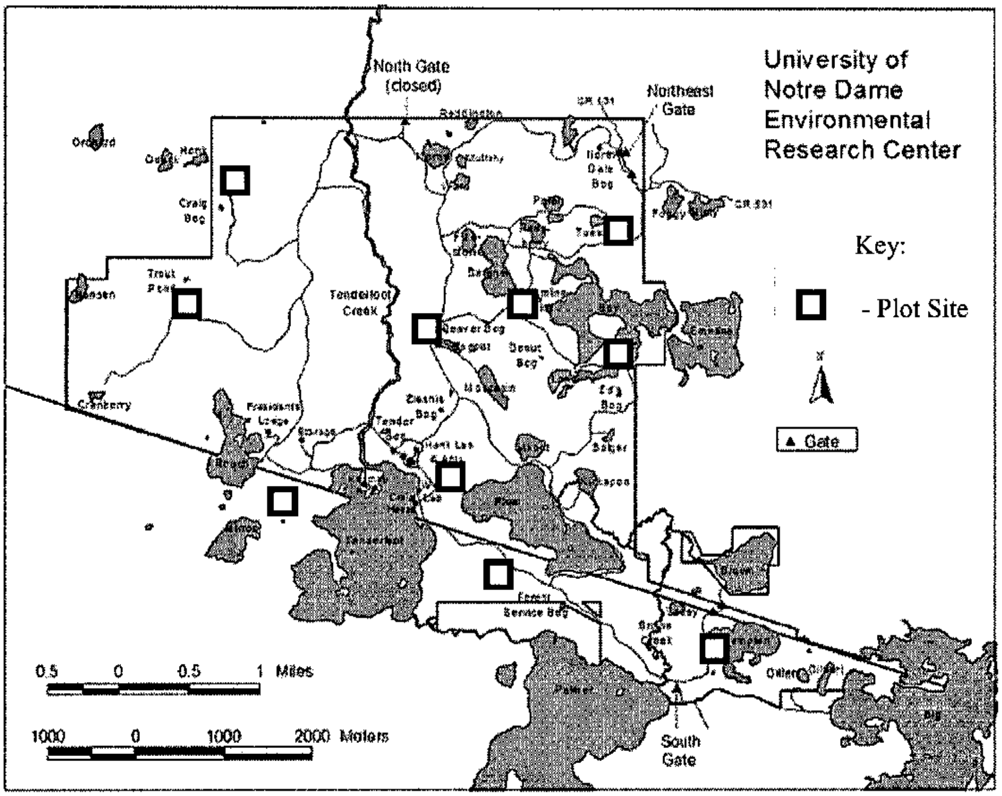


Figure 1: Map of Tested Area (UNDERC Property)

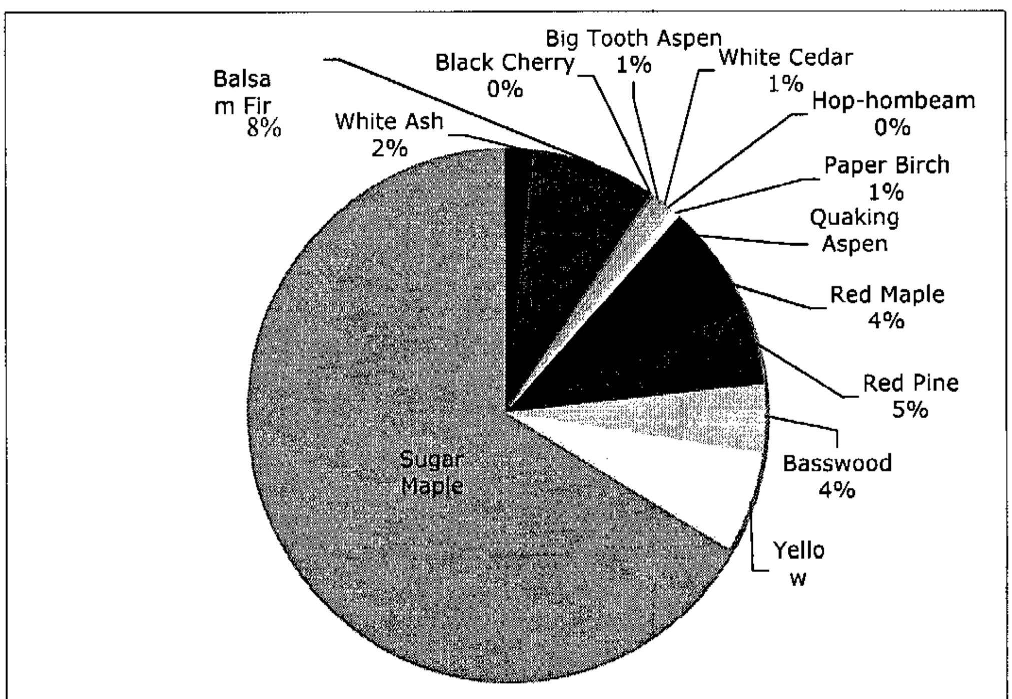


Figure 2: Tree Species of the UNDERC Forest

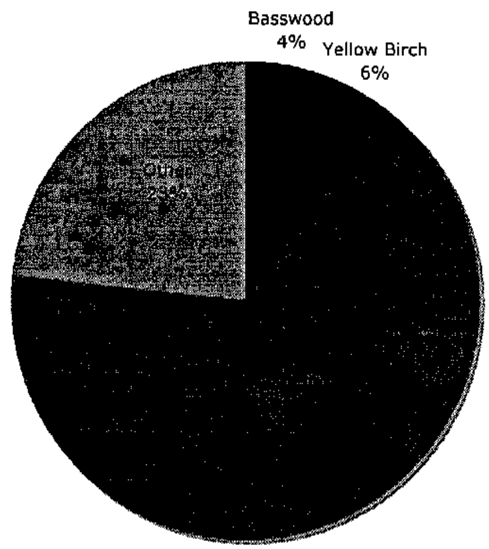
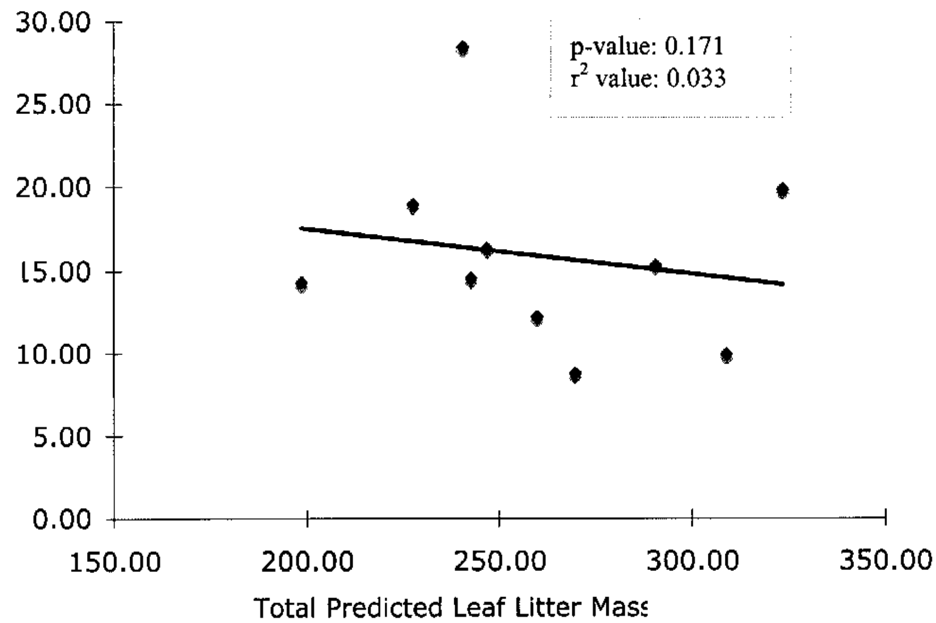
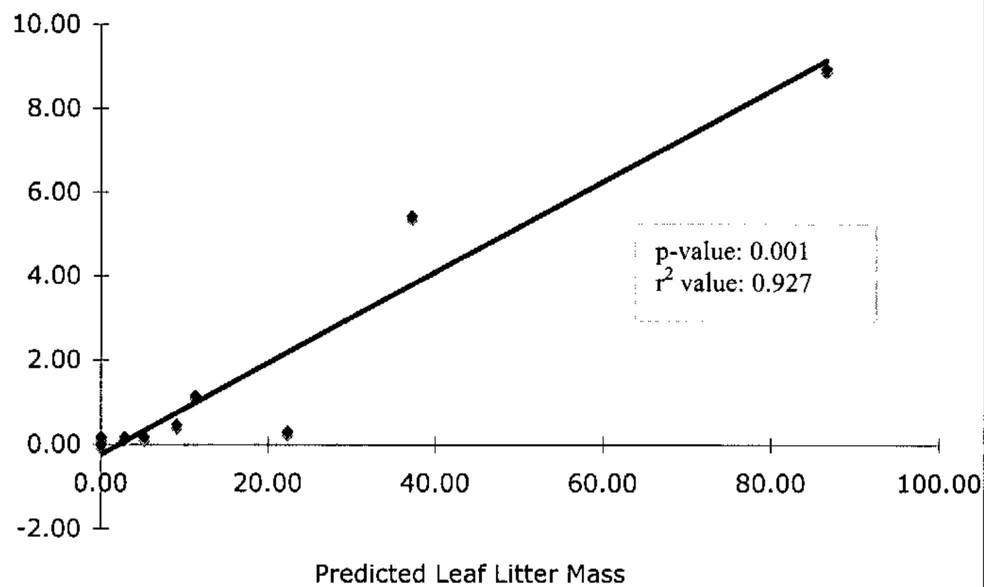


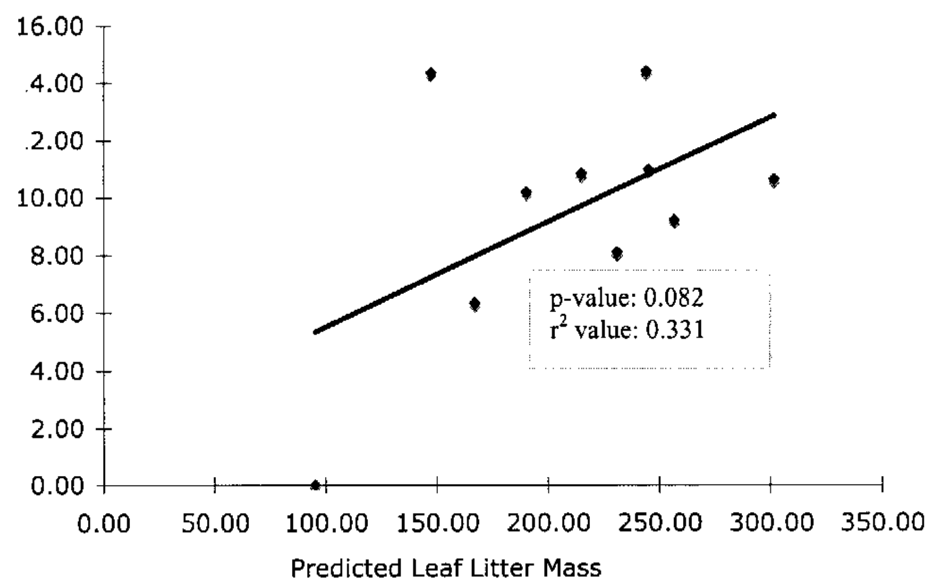
Figure 3: Proportions of Analized Trees Throughout UNDERC Property



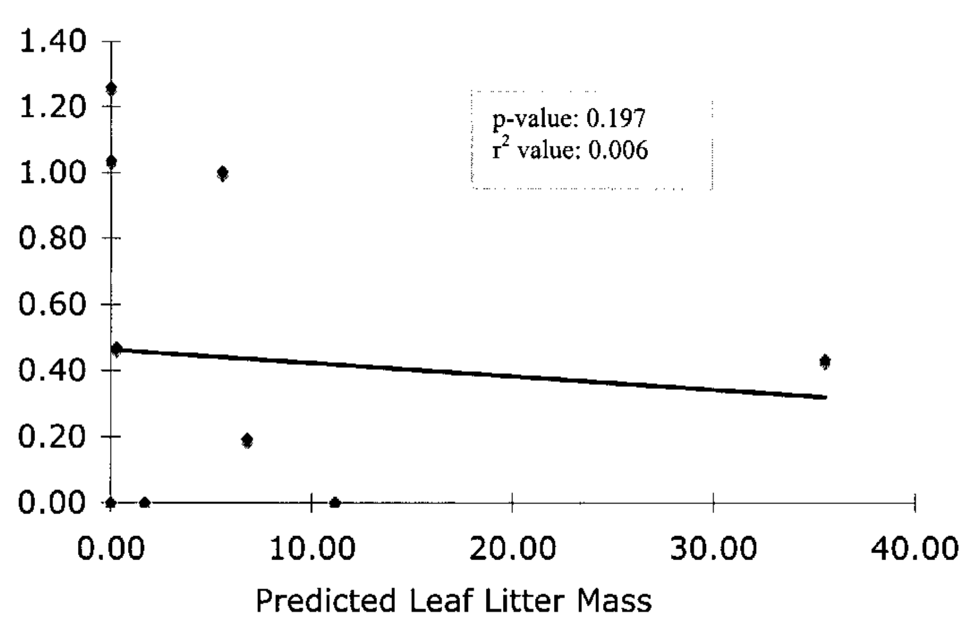
Graph 1: Total Litter Regression- Predicted Litter Effects on Sample Total Litter



Graph 2: Yellow Birch Regression- Predicted Litter Effects on Sampled Litter



Graph 3: Sugar Maple Regression- Predicted Litter Effects on Sampled Litter



Graph 4: Basswood Regression- Predicted Leaf Litter Effects on Sampled Leaf Litter

Species List

Paper Birch -- *Betula papyrifera*
Quaking Aspen -- *Populus tremuloides*
Big-tooth Aspen -- *Populus grandeidentata*
Black cherry -- *Prunus serotina*
White ash -- *Fraxinus nigra*
Yellow birch -- *Betula alleghaniensis*
Hop-hornbeam -- *Ostrya virginiana*
Basswood -- *Tilia americana*
Sugar maple -- *Acer saccharum*
Red maple -- *Acer rubrum*
Red pine -- *Pinus resinosa*
Balsam fir -- *Abies balsamea*
White cedar -- *Thuja occidentalis*

Formulas and Calculations

Formula 2: Calculations for Predicted Leaf Litter Fall per Tree (Ferrari (1996))

$$\text{Total Leaf Litter} = \sum [(\alpha\gamma^2 \div 2\pi) \times (DBH)^{\beta} \exp((-\gamma z - \delta(DBH))]$$

Table 1: Leaf Litter-fall model Parameters Adopted from Ferrari (1996)				
	Tree Species			
Estimated constants	Sugar Maple	Yellow birch	Basswood	Hemlock
α	22.7681	3.3729	3.2022	0.5097
ß	1.9607	2.4907	2.3546	2.6411
γ	0.2348	0.2186	0.2101	0.2422
δ	0.0275	0.0337	0.0320	0.0309

Z – Distance from tree (m)