Comparing an Oak-hickory and Northern Hardwood Ecosystem: An Analysis of How Climate and Physiography Influence Soil Properties and Processes in Two Distinct Forest Ecosystems in Lower Michigan

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ABSTRACT

Forest ecosystems are complex and dynamic systems that are shaped by a multitude of different biotic and abiotic factors (Christopherson, 2009; Schoenholtz, 2000).To analyze the factors influencing ecosystem variation, this study compared the soil properties and processes, as well as vegetative composition of two forest ecosystems in lower Michigan. The sites selected for analysis were an oak-hickory (OH) and northern hardwood (NH) ecosystem, both of which differ in latitude, elevation, proximity to water, landform, and parent material. Evaluation between ecosystems was specifically based on site observations, soil and vegetation samplings, and soil profile analyses conducted in the field, as well as on extensive laboratory analyses that determined the physical, chemical, and biological processes of soil. Despite the physical, chemical, and biological differences concluded between the OH and NH sites, both ecosystems were found to support similar vegetative communities, dominated by *Quercus rubra* and *Acer saccharum.* Given the sandier soil content and shorter growing season in the NH ecosystem, it would be assumed that the overall productivity and composition of the NH site would also be different from the OH ecosystem, and would not support such water- and nutrient-needy plants. However, the NH ecosystem was found to support significant levels of of both ecosystem biomass and nitrogen in aboveground (249.628 Mg C/ha and 635.458 kg N/ha respectively), forest floor (12.64 Mg C/ha and 112.492 kg N/ha respectively), and belowground pools (43.979 Mg C/ha and 2498.8 kg N/ha respectively) when compared to the OH ecosystem (121 Mg C/ha and 254 kg N/ha aboveground, 7.83 Mg C/ha and 40.836 kg N/ha forest floor, and 72.669 Mg C/ha and 1294.2 kg N/ha belowground). Total basal area of the dominant overstory tree species was also larger for the NH ecosystem than the OH ecosystem. The NH ecosystem is able to support such a significant vegetative community—and one that is so similar in species composition to the OH ecosystem—because the site experiences low levels of water and nutrient loss due to infrequent disturbance and the creation of microclimates from the rolling topography. Likewise, the vegetative growth is affected on the OH site due to the high percentage of coarse fragments in the soil and the more drastic topographical undulations which result in microclimates with high rates of runoff and evaporation, and therefore lower rates of nutrient retention. From observations and analyses conducted in this study, it can be concluded that climate and physiography are significant factors affecting the soil formation, vegetative composition, and overall ecosystem structure in both the OH and NH ecosystems, and that such influences contribute to similar vegetative structures between ecosystems that are otherwise very different. The findings in this study support the importance of climate and physiography as key influences on soil formation, vegetative composition, and overall ecosystem structure and productivity, and illustrate the extent to which local forest ecosystems could be altered in the face of future climate and landform alterations.

INTRODUCTION

Understanding the complex nature of a forest ecosystem necessitates an equally complex and comprehensive analysis of the components which contribute to that ecosystem's existence. Soil is the foundation upon which terrestrial ecosystems are supported (Zak, 2010), making it a crucial factor of consideration in ecosystem analysis. Soil's physical, chemical, and biological properties all contribute to the vegetative and microbial composition present within a particular forest ecosystem (Knoepp, 2000). These properties of soil, however, are largely influenced by other factors, such as climate and physiography (Host, 1987; Pastor and Post, 1988l; Seybold, 1998).

Climate is one of the foremost factors influencing the physical, chemical, and biological properties of soil within forest ecosystems. Together with the physiography of the land, climate affects the health and productivity of ecosystems via temperature, precipitation, and evapo-transpiration (Pastor and Post, 1988). These factors influence water and nutrient retention and availability, microbial presence, and vegetative composition and growth within an ecosystem (Pastor and Post, 1988). Climatic variations occur as a result of latitude, elevation, and proximity to water bodies, and can be witnessed in the differing patterns of vegetation distributed across the earth (Barnes et al., 1998; Fisher and Binkley, 2000).

Although factors associated with climate contribute significantly to ecosystem processes and productivity, physiography's role in shaping soil formation—and therefore forest ecosystems at large—is also significant (Host, 1987). Glacial history sculpted the earth's surface, and has left behind various landforms with different topographic profiles (Menzies, 2002). These variations in topography have the ability to create localized microclimates, which in turn, have an effect on soil formation and ecosystem processes and productivity (O'Brien, 2003). Landform is also directly related to the parent material present in an ecosystem, which is another critical factor influencing the physical and chemical properties of soil (Menzies, 2002). Parent material relates to soil's nutrient and water holding capability, which is critical for ecosystem productivity (Anderson, 1988; Fisher, 2000).

This study addresses how soil formation and processes are influenced by climate and physiography, by comparing two forest ecosystems in lower Michigan. The two ecosystems selected for comparison include: an oak-hickory (OH) ecosystem located in southeastern lower Michigan, and a northern hardwood (NH) ecosystem located in northwest lower Michigan. The latitudinal and elevational gradient between the two sites in study facilitate a climatic analysis, as does the NH ecosystem's proximity to Lake Michigan. The landform and parent material present at each site is also distinct—with the OH ecosystem consisting of calcareous ice contact material formed on kettles and kames landforms, while the NH ecosystem is formed on a recessional moraine with glacial till parent material.

A combination of field and laboratory analyses was conducted for both ecosystems in comparison. Specific investigation into the physical, chemical, and biological properties of soil within the oak-hickory (OH) and northern hardwood (NH) ecosystem was conducted, and analysis was conducted on how factors such as climate and physiography influence soil formation, and subsequently, forest ecosystem structure, processes, and productivity.

METHODS

Study Site Descriptions

To analyze the different factors influencing forest ecosystems, data was collected from two separate field sites representing two distinct ecosystems present in Michigan—oak-hickory (OH) and northern hardwood(NH).

The first site sampled was an oak-hickory (OH) ecosystem at Stinchfield Woods in Washtenaw County, Michigan. Located approximately at 42 degrees North, this ecosystem experiences a mean average temperature of58.1 degrees Fahrenheit to 36.1 degrees Fahrenheit and precipitation average of 39 inches (National Climatic Data Center). Stinchfield Woods is posited on a well-sorted glacial kame with ice contact parent material, giving rise to an undulating topographic landscape rich with microclimates and well-drained, calcareous soils. The dominant tree species in the overstory at Stinchfield Woods include: *Quercus rubra*, *Quercus alba*, *Carya ovata*, and *Carya glabra*, classifying it as an oak-hickory (OH) ecosystem. The specific soil pit where sampling occurred is located in the mid-portion of a steep (78 percent) Northeast-facing slope.

The site sampled for comparison was a northern hardwood (NH) ecosystem in Manistee National Forest in Wexford County, Michigan. Located between 43 and 45 degrees North (USDA Forest Service), this ecosystem runs parallel to Lake Michigan and is the highest elevation in lower Michigan (approximately 150 feet higher than the OH ecosystem) (Zak, 2010). The site experiences a mean average temperature of 55.9 degrees Fahrenheit, whereas the annual mean minimum was 34.1 degrees Fahrenheit and average precipitation of 40 inches per year (National Climatic Data Center; USDA Forest Service). Located on a recessional moraine, Manistee National Forest has gently-rolling microtopography composed of glacial till parent material that was deposited by the Wisconsin glacier (Larson et al., 2001). The site is a relatively undisturbed, stable, late successional ecosystem, characterized by well-developed soil and similar tree species occurring in both the over- and understory (Zak, 2010). The dominant tree species at the site include: *Acer saccharum*, *Tilia americana*, *Quercus rubra*, *Tsuga canadensis*, *Fagus grandifolia*. The soil at the site is a relatively young (approximately 8,000 years old) previously-sorted spodosol, which makes drainage rapid due to its predominately sandy content (Zak, 2010). Specific sampling in this ecosystem occurred on a lower Northwest-facing (33 percent) slope.

Field Data Collection

In order to analyze and compare the oak-hickory (OH) and northern hardwood (NH) ecosystems, field data related to vegetation and soil was collected from each of the sites described above. Sampling occurred in a 15m by 30m plot that was representative of, yet selected at random from, each ecosystem. Upon arrival at the site, general site analyses were conducted to record slope, aspect, and physiographic location in the landscape.

Each plot within each of the ecosystems contained a soil pit, where analysis of the soil profile occurred. The top organic layer was analyzed in terms of depth, level of decomposition, and type of organic material. In the pit at each of the sites, soil horizons were differentiated and depths of each horizon subsequently measured. Soil texture, structure, color, pH, boundary, and percent coarse fragments were also determined and recorded.

A series of soil cores with a 1cm radius and 10cm depth were also extracted at random from within each of the plots, to be used towards later laboratory analysis. Two larger soil cores, with a 5cm radius and 10cm depth, were also extracted from each plot in order to determine soil bulk density.

To analyze the vegetation within each of the ecosystems, the species and diameter at breast height (DBH) were recorded for each tree within each of the site's plot that exceeded 10cm DBH. Two samples of forest floor material were also collected within each plot by gathering the aboveground organic matter located within a randomly placed 2,809cm^2 frame.

Laboratory Analyses

After field data and samples were collected from the OH and NH sites, a series of laboratory analyses were conducted to determine the physical, chemical, and biological properties of each of the ecosystems.

<u>Physical Properties</u>

The physical soil properties analyzed included: texture, available water content, and bulk density. Before analyses began, soil samples were first passed through a sieve to remove any remaining coarse fragments that exceeded 2mm in diameter.

Soil texture was determined for each of the ecosystems by using the hydrometer method and Stoke's Law ($V = kr^2$), which quantifies the concept that larger particles settle at a more rapid rate than particles of a smaller size. To do so, a portion of the soil samples collected from each ecosystem (98.55g for OH and 99.38g for NH) were measured out and blended with a 100mL solution of sodium hexametaphosphate and tap water for 5 minutes to break up existing aggregates and thoroughly mix together particles. The blended solution, along with an additional 1L of water was then transferred to a glass sedimentation cylinder and thoroughly plunged. Hydrometer readings were taken at 40 seconds to determine the amount of silt and clay still present within the soil after the sand settled out, and a 2 hour hydrometer reading was taken to determine how much clay remained in the soil after both the sand and silt settled out.

Available water content (AWC) was determined for each of the ecosystems by placing a saturated soil sample from each site onto a ceramic plate to measure field capacity (by exerting 0.01 MPa of pressure) and onto a separate ceramic plate to determine the permanent wilting point (by exerting 1.5MPa of pressure). The AWC was calculated as the difference in mass between the field capacity (FC) and the permanent wilting point (PWP).

Lastly, the bulk density of the OH and NH soil was calculated. This was done by dividing the mass of an oven-dried sub-sample of soil from each ecosystem by the volume of the soil core used in the field (with a 5cm radius and 10cm depth).

Chemical Properties

The chemical soil properties analyzed in the laboratory included: pH, organic matter content, cation exchange capacity (CEC), and base saturation.

Soil pH was measured by inserting a glass electrode into a 1:1 soil-to-deionized water paste, as well as into a 1:1 soil-to-0.01M $CaCl_2$ paste.

Soil organic matter for each ecosystem was determined via the wet combustion method, where H_2SO_4 and $K_2Cr_20_7$ were utilized to oxidize the soil organic matter. A spectrometer was then employed to measure the amount of reduced dichromate ion, which is proportional to the organic matter content. The amount of organic carbon (mg) was then calculated by finding the linear regression between the log of transmittance and carbon content (mg C) present in five carbon standards (of 1, 2, 4, 6, and 8mL of 4mg C/mL sucrose standard solution).

The CEC was determined by measuring the exchangeable acidity and the base cation concentration of the soil collected from each site. Exchangeable acidity was measured by using 25mL of 1M KCl to saturate a sample of soil from each ecosystem. This removed the base cations from the CEC. Soil particles were then removed via filtration, and a phenolphthalein indicator was added. The solution was then titrated with 0.04M NaOH until $[H^+]$ = [OH], as indicated by the color of the solution changing to a permanent pale pink. To correct for the fact that KCl contains its own level of acidity, a blank solution containing only KCl was titrated with 0.04M NaOH. This “blank” measurement was subsequently subtracted from the original measurement, yielding a corrected measurement of exchangeable acidity of the soil. In order to determine the base cation concentration of the soil, the CEC was then saturated with 1M NH_4Cl, filtered, and run through an Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES). The ICP-OES determined the concentrations of

Ca2+, Mg2+, K+, and Na+ in the soil samples. The exchangeable acidity and the base cation concentration were then added together to determine the overall CEC for each ecosystem.

Lastly, base saturation of the soil from each ecosystem was determined by calculating the percentage of CEC occupied by base cations.

Biological Properties

Biological properties of soil were also investigated in order to analyze and compare the OH and NH ecosystems. Biological analyses included: microbial biomass, microbial respiration, net nitrogen mineralization and net nitrification, nutrient pools, and biomass.

Microbial biomass present within the soil at each site was calculated by comparing the CO_2 concentrations of a chloroform fumigated “F” soil sample with that of a control “C” sample from each ecosystem. To do so, 30g of both an F and C sample of soil from each site were measured and brought to field capacity. After the F sample sat for 20 hours in a vacuum dessicator with chloroform, the chloroform vapor was removed, then inoculated with 1g of soil from the C sample, and then incubated along with the C sample for 2 weeks at room temperature. After the two week incubation period, a gas chromograph was used to determine the CO_2 concentration within each of the jars, and the microbial biomass was calculated by subtracting the concentration of CO2 in the F sample from that in the C sample and dividing by a correction factor (K_c) of 0.45.

Microbial respiration was then calculated by subtracting the amount of CO_2 found in the C sample from the background (atmospheric) level of CO_2, multiplying by the volume of the incubation jars, and dividing that product by the oven-dry weight of the soil sample multiplied by the number of days held in incubation (13 days).

To determine the net nitrogen mineralization and net nitrification, the soil samples were removed from incubation, 60mL of 2M KCl was added to the C samples, and then shaken to dissolve the nitrogen in the solution. A Rapid Flow Analyzer was then used to determine the amount of NH^{4+} -N and NO^{3-} -N in the filtrates. These amounts were then adjusted to account for the previous extraction of the inoculum from the C sample. Net nitrogen mineralization was calculated by subtracting the amount of ammonium and nitrate in the C sample from the amount of ammonium and nitrate in the F sample for each ecosystem, and dividing by the number of days held in incubation (14 days). Net nitrification was then calculated by subtracting the amount of nitrate in the C sample from the amount of nitrate in the F sample for each ecosystem, and dividing by the number of days in incubation (14 days).

The final biological analyses conducted on the soil samples from the OH and NH ecosystems were measurements of the aboveground, forest floor, and belowground biomass and nitrogen content at each site.

Aboveground biomass (the estimated weight of boles, branches, and leaves of each tree species per hectare) was determined by using previously recorded DBH measurements from the field. The organic matter samples collected in the field using the 2,809cm^2 frame were weighed and converted to a per hectare value to determine the forest floor biomass at each site. The belowground biomass (the weight of the soil organic matter (Mg/ha) in the top 10cm of soil) was calculated by using the previously determined bulk density and percent organic matter measurements from each site. Aboveground, forest floor, and belowground nitrogen contents (kg N/ha) were also determined for each ecosystem. These values were calculated by multiplying the biomass of each pool by predetermined nitrogen percentages of each tree species.

RESULTS

Field Data Results

Field analyses were conducted to determine landform and parent material, soil characteristics, and vegetative composition of each ecosystem. It was determined that the oak-hickory (OH) ecosystem occurred on kettle and kame landforms with poorly-sorted, calcareous ice contact parent material. The NH ecosystem, in comparison, was formed on a recessional moraine landform, on previously-sorted glacial till parent material.

OH soil profile analysis revealed upper horizons that were loamy and slightly acid that transitioned into more alkaline clayey horizons as depth increased. The presence of a B_t horizon confirmed the presence and accumulation of clay in the OH soil profile. There was also a significant percentage of coarse fragments present within the OH soil profile layers (1 to 90 percent), which contributed to the overall weak structure of the soil. The NH soil profile, in comparison, consisted of much sandier soils that were more acid overall. The presence of both a $B_{h,s}$ and a B_s horizon indicated the accumulation of humus and sesquioxides in deeper soil layers. The NH ecosystem did not contain coarse fragment, but still had a relatively weak structure given the high sand content. (See Appendix I and II for complete soil profile descriptions)

The vegetation present at the OH ecosystem sample plot is fairly diverse, as illustrated by the relative overstory species dominance recorded below in Figure 1. The overstory of the OH ecosystem is dominated by oaks (*Quercus alba* and *Q. rubra)* and hickories (*Carya ovata* and *C. glabra)*. The understory of the OH ecosystem consisted primarily of shrubs and groundcovers such as *Viburnum rafinesquianum*, *Rhus aromatica*, *Rubus occidentalis*, *Toxicodendron radicans*, and *Smilax tamnoides*. The particular sample plot (located on the mid-portion of a North-facing slope) supports a dense and diverse array of vegetation as compared to other sites within the ecosystem. Sites located on the upper-portions of the slopes, as well as those sites located on the South-facing side of the slope, support a much sparser amount of vegetation that is primarily dominated by *Carix pensylvanica*, *Ribes cynosbadi*, and *Quercus prinoides*.

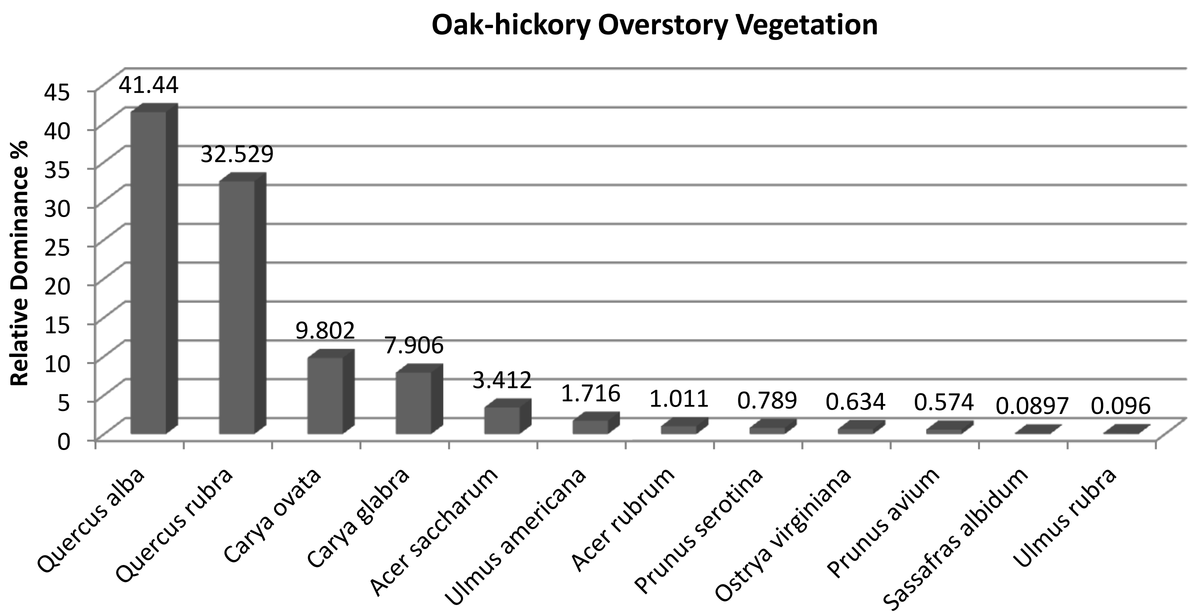

Figure 1: Oak-hickory Ecosystem Overstory Relative Dominance

Comparatively, the overstory of the NH ecosystem was dominated by *Quercus rubra*, *Fagus grandifolia*, *Acer saccharum*, and *Tsuga canadensis*, which is represented in Figure 2 below. The total basal area for these dominant overstory species was determined to be 40.933 m^2/ha. The understory of the NH ecosystem was comprised of *Acer saccharum*, *Fraxinus americana*, *Fagus grandifolia*, *Prunus serotina*, *Sassafras albidum*, and *Ostraya virginiana* saplings.

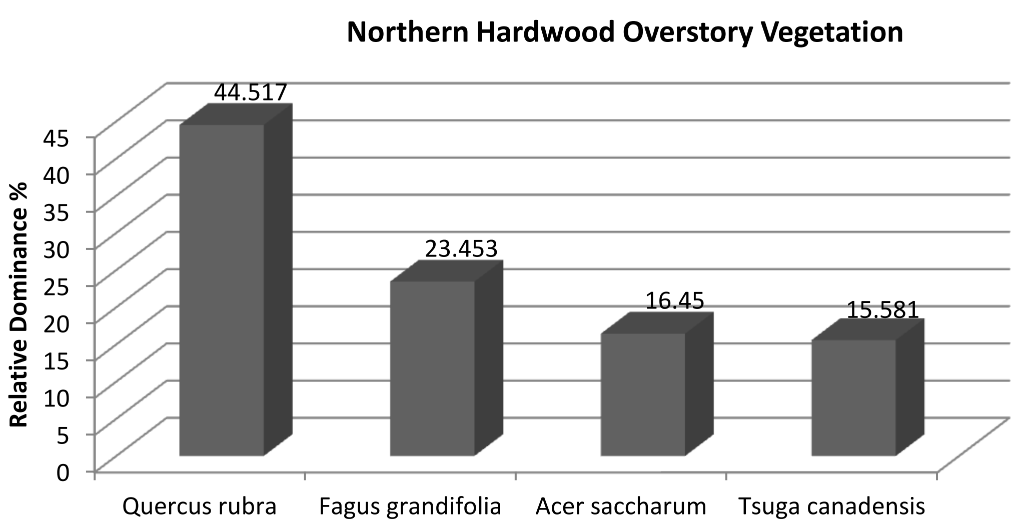

Figure 2: Northern Hardwood Ecosystem Overstory Relative Dominance

Laboratory Results

Physical Properties

Laboratory analyses confirmed that soil texture for the OH ecosystem was sandy loam, and sand for the NH ecosystem. As illustrated in Figure 3 below, the OH ecosystem had a higher proportion of silt (30.45 percent) and clay (11.16 percent) compared to the NH ecosystem (which had 8.06 percent silt, and 2.01 percent clay). The NH ecosystem had a higher proportion of sand (89.93 percent) than did the OH ecosystem (58.39 percent).

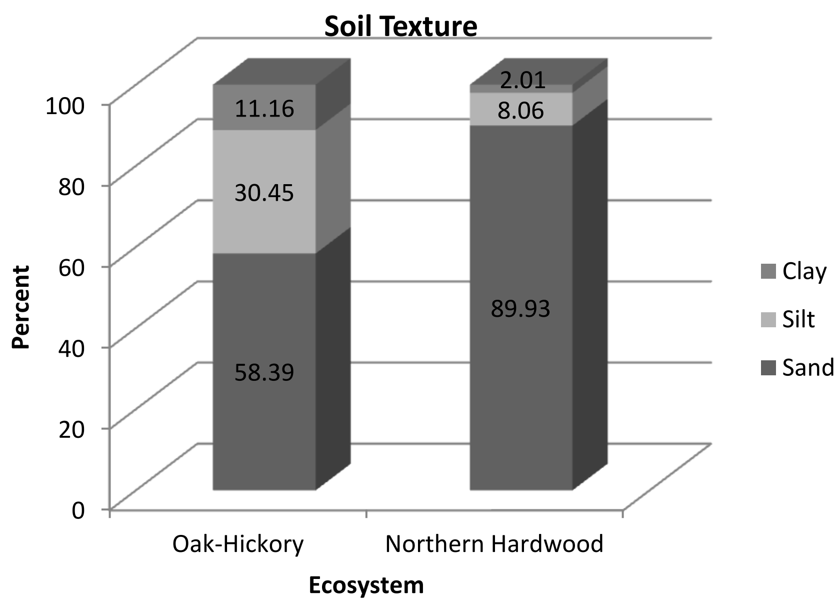

Figure 3: Soil Texture Analysis

The available water content (AWC) of the OH ecosystem (0.4793 $cm^3 H_2 0/cm^3$soil) was measured and found to be higher than that of the NH ecosystem's AWC (0.26 cm^3H20/cm^3soil). The bulk density was relatively similar for both ecosystems, although slightly higher for the OH ecosystem (1.0785 g/cm^3) than for the NH ecosystem (0.9799 g/cm^3). A summary of the physical soil properties determined through laboratory analyses can be found below in Table 1.

Physical Properties

Site	**Texture**	**AWC** ***($cm^3 H_2 0/cm^3$soil)***	**Bulk Density** ***(g/cm^3)***
Oak-Hickory	Sandy loam	0.4793	1.0785
Northern Hardwood	Sand	0.26*	0.9799

Table 1: Soil Texture, Soil Water, and Bulk Density Data
*Indicates data collected from lab group averages

Chemical Properties

A series of laboratory analyses were also conducted to determine the chemical properties of the soil from the OH and NH ecosystems. The laboratory results for soil pH were consistent with those conducted in the field, concluding that the average soil pH was higher in the OH ecosystem (5.3) than in the NH ecosystem (3.5). The percent organic matter was also determined to be higher at the OH site than at the NH site. Table 2 (below) summarizes the pH values and organic matter content determined for each of the ecosystems.

pH and Organic Matter

Site	**Water pH**	**$CaCl_2$ pH**	**% Organic C**	**% Organic Matter**
Oak-Hickory	5.62	4.98	3.369%	6.738%
Northern Hardwood	3.83	3.18	2.024%	4.048%

Table 2: pH and Organic Matter Data

Total acidity, cation exchange capacity (CEC), and base saturation were also determined for both the OH and NH ecosystems. Table 3 (below) summarizes these results. Total acidity was found to be significantly higher in the NH ecosystem (1.154 cmol(+)/kg) than in the OH ecosystem (0.018 cmol(+)/kg). CEC and base saturation, however, were concluded to be higher in the OH ecosystem than in the OH ecosystem. CEC of the OH ecosystem (9.217 cmol(+)/kg) was significantly higher than that of the NH ecosystem (2.924 cmol(+)/kg). The base saturation measurements for the OH ecosystem (99.8%) indicated that majority of the exchangeable sites in the soil were already occupied by base cations, as compared to the NH ecosystem which only had 60.53% of the exchangeable sites occupied. These results are summarized in Table 3 below.

Total Acidity, CEC, and Base Saturation

Site	**Total Acidity *(cmol(+)/kg)***	**CEC *(cmol(+)/kg)***	**Base Saturation (%)**
Oak-Hickory	0.018	9.217	99.8%
Northern Hardwood	1.154	2.924	60.53%

Table 3: Acidity, CEC, and Base Saturation Values

Biological Properties

The final set of laboratory analyses used to compare the OH and NH ecosystems pertained to soil's biological properties. These analyses included: ecosystem biomass and nutrient pools, soil microbial biomass and respiration, and net nitrogen mineralization and net nitrogen nitrification.

Table 4 (below) summarizes the amount of ecosystem biomass and nutrient pools that were found in aboveground, forest floor, and belowground pools in both the OH and NH ecosystems.

Ecosystem Biomass and Nutrient Pools

Site	Aboveground C *(Mg/ha)*	Aboveground N *(kg N/ha)*	Forest Floor C *(Mg/ha)*	Forest Floor N *(kg N/ha)*	Soil C *(Mg/ha)*	Soil N *(kg N/ha)*
Oak-Hickory	121*	254*	7.83*	40.836	72.669	1,294.2
Northern Hardwood	249.628	635.458	12.64*	112.492	43.979	2,498.8

Table 4: Ecosystem Biomass and Nutrient Pools
*Indicates data collected from lab group averages

Figure 4 specifically presents measurements and proportions that were determined for levels of ecosystem biomass located aboveground, on the forest floor, and belowground. As shown in the table, biomass concentrations were higher in the NH ecosystem in the aboveground (635.458 Mg/ha), forest floor (12.64 Mg/ha), and belowground (72.669 Mg/ha) pools compared to the OH ecosystem's aboveground (121 Mg/ha), forest floor (7.83 Mg/ha), and belowground (43.979 Mg/ha) pools. As seen in Graph 4, the NH ecosystem has a higher proportion of biomass in aboveground pools compared to the OH ecosystem, and the OH ecosystem contains more biomass belowground than does the NH ecosystem.

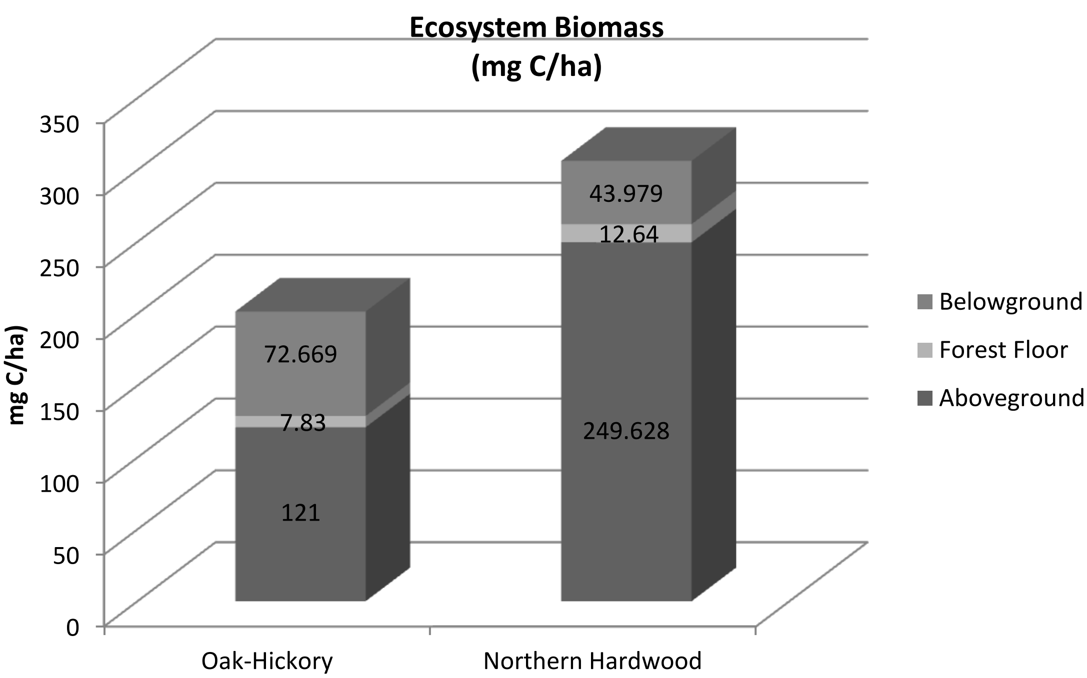

Figure 4: Ecosystem Biomass(mg C/ha) for OH and NH Ecosystems

Similar trends were observed amongst the nutrient pools in the OH and NH ecosystems. Figure 5 shows that, overall, the NH ecosystem contained higher levels of nitrogen in the aboveground (635.458 kg N/ha), forest floor (112.492 kg N/ha), and belowground (2498.8 kg N/ha) pools than the OH ecosystem's aboveground (254 kg N/ha), forest floor (40.836 kg N/ha), and belowground (1294.2 kg N/ha) pools. The NH ecosystem again contained a higher proportion of nitrogen in aboveground pools compared to OH's aboveground pools, while OH possessed a higher proportion of nitrogen in the belowground pools than the NH's belowground pools.

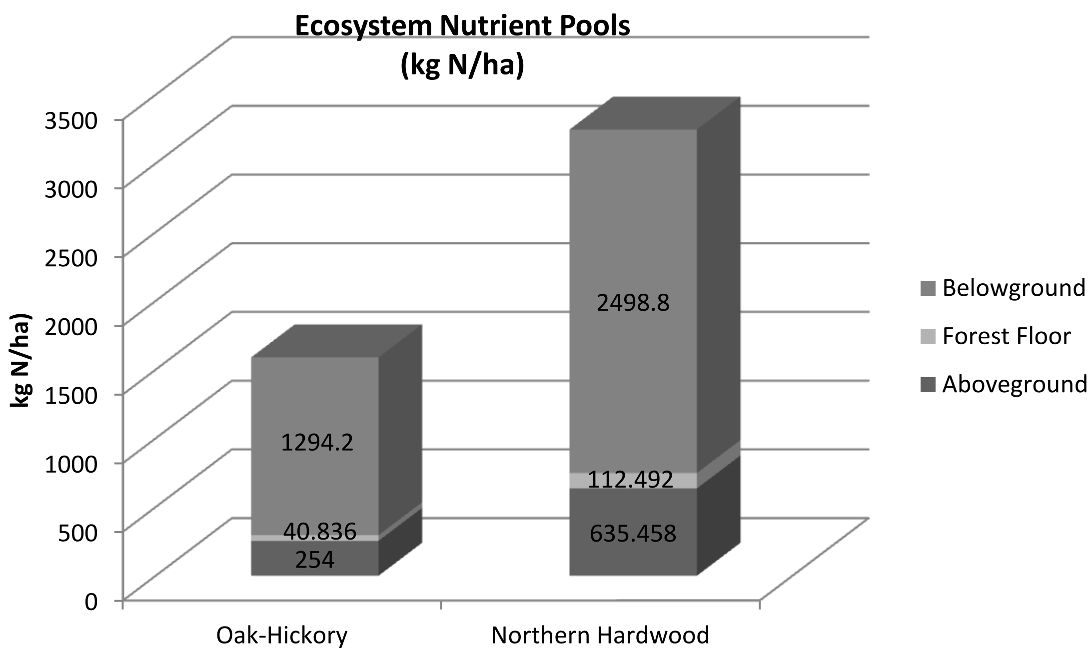

Figure 5: Ecosystem Nutrient Pools (kg N/ha) for OH and NH Ecosystems

Table 5 (below) summarizes levels of microbial biomass and microbial respiration in each of the ecosystems. As shown in the table, microbial biomass is higher in the NH ecosystem (93.186 ug C/g) compared to OH's microbial biomass (89.540 ug C/g). Microbial respiration, however, was found to be higher in the OH ecosystem (51.742 mg C/g/d) than in the NH ecosystem (24.896 mg C/g/d). These measurements were conducted to help explain how activity amongst the microbial community contributes to the production of nitrogen within each ecosystem.

Soil Microbial Biomass and Respiration

Site	**Microbial Biomass (ug C/g)**	**Microbial Respiration (mg C/g/d)**
Oak-Hickory	89.540*	51.742
Northern Hardwood	93.186*	24.896

Table 5: Soil Microbial Biomass and Respiration Rates
*Indicates data collected from lab group averages

Mineralization and nitrification rates were also measured for the OH and NH ecosystems to help determine the rate at which nutrients cycle through each ecosystem. Table 6 (below) shows net N mineralization and net N nitrification results that were concluded from laboratory analyses. OH was found to have a higher net nitrogen mineralization rate (0.410 g N/d/ m^2) than the NH ecosystem (0.210 g N/d/ m^2), which is a measure of the amount of nutrients available. Conversely, the net nitrogen nitrification rate was found to be higher in the NH ecosystem (0.178 g N/d/m^2) than in the OH ecosystem (0.081 g N/d/m^2).

Mineralization and Nitrification Rates

Site	**Net N Mineralization (g N/d/m^2)**	**Net N Nitrification (g N/d/m^2)**
Oak-Hickory	0.410	0.081
Northern Hardwood	0.210	0.178

Table 6: Net Mineralization and Net Nitrification

DISCUSSION

Physical Properties

Despite the differences in latitude, elevation, proximity to bodies of water, landform, and parent material, both the OH and NH ecosystems support relatively similar vegetative communities. Given the sandier soil content and shorter growing season due to higher latitude and elevation in the NH ecosystem, it would be assumed that the overall productivity of the NH ecosystem would be less than that of the OH ecosystem. However, analysis of the relative dominance of overstory tree species and total stand basal area within the test plots reveal that, regardless of these adverse growing conditions, the NH ecosystem manages to support a significant presence of vegetation that is strikingly similar to that of the OH ecosystem in southern lower Michigan. Both sites are comprised of similar tree species that require high nutrient and water inputs, such as *Quercus rubra*, *Acer saccharum*, *Prunus serotina, Fagus grandifolia*, *Ostraya virginiana*, *Sassafras albidum* (Barnes and Wagner, 2007). The presence of such a significant vegetative community in the NH ecosystem implies that additional factors, such as climate and physiography, must be influencing soil formation and ecosystem structure.

Average annual precipitation rates between the two ecosystems are relatively similar (39 inches for OH and 40 inches for NH), indicating that the productivity of NH as it relates to the OH site is a function of additional climatic factors (National Climatic Data Center; USDA Forest Service). The NH site is located just inland from Lake Michigan, producing a cool, moist climate (USDA Forest Service). Although the average temperatures in the NH ecosystem are lower and the growing season foreshortened compared to the OH ecosystem, these colder temperatures actually help facilitate higher water and nutrient retention due to decreased evapo-transpiration rates (Brady and Weil, 2002).

The differences in nutrient and water holding capacity at both the OH and NH ecosystems are also a result of the physiography of each site (Host, 1987). The NH ecosystem is posited on a recessional moraine, which is a relatively undulating landscape (Menzies, 2002). This microtopography facilitates the existence of microclimates which, in turn, allow for decreased evapo-transpiration and increased water retention that facilitate plant growth (O'Brien, 2003). This type of landform also creates a protective topography that has helped to shield the NH ecosystem from frequent disturbance such as fire, thus facilitating higher nutrient retention (Zak, 2010). The kettle and kame landforms that the OH ecosystem is bedded on also create a rolling landscape with microclimates. The topography of the OH ecosystem is more drastic than that of the NH ecosystem, however, with higher sun exposure and rates of evaporation occurring on the tops of landforms and on the south-facing slopes, resulting in less water availability and limited vegetative growth than would be usual for a more loamy soil (Grayson and Bloschl, 2000; Tromp, 2006). Although the soil texture of the OH ecosystem had a higher percentage of silt (30.45 percent) and clay (11.16 percent) compared to the NH ecosystem (8.06 percent silt and 2.01percent clay), the soil within the OH ecosystem also contained a high percentage of coarse fragments and therefore pore space, which facilitates higher percolation rates of water (Brady and Weil, 2002; Brakensiek and Rawls, 1994).

Chemical Properties

The parent material underlying both ecosystems in comparison also has a large impact on the chemical properties of the soil found within each site (Fisher, 2000). Parent material, coupled with organic matter content, affects the presence of H^+ ions, which is reflected in the soil's pH (Brady and Weil, 2002). The calcareous limestone-based parent material and high percentage of organic matter of the OH ecosystem (6.738 percent) contribute to its more alkaline pH (5.3) (Fisher, 2000). The soil pH of the NH ecosystem, in contrast, originates from sandy glacial till parent material that is more silica-rich, yielding a significantly more acidic pH (3.5) and higher total acidity (1.154 cmol(+)/kg).

Cation exchange capacity (CEC) is also linked to parent material, and is a measure of the total of exchangeable cations a soil can absorb (Brady and Weil, 2002; Zak, 2010). Soils with higher clay content reflect higher CECs (Helling et al., 1963), since the surface area of clays is much greater and the overall charge is net negative, allowing for a larger area for cation absorption to occur (Brady and Weil, 2002). Higher percentages of organic matter content also contribute to higher CEC, since organic matter also has a high potential to hold cations (Brady and Weil, 2002; Helling et al., 1963). The higher CEC at the OH ecosystem (9.217 cmol(+)/kg as compared to 2.924 cmol(+)/kg in the NH ecosystem) can therefore be attributed to its high clay content, as well as to the higher percent organic matter. Sandy soils, like those found in the NH ecosystem, have a lower ability to absorb cations due to the much smaller surface area and fewer exchange sites, which explains the lower CEC observed at the NH site (Brady and Weil, 2002; Zak, 2010). However, the NH site still possesses a fair amount of organic matter (4.048 percent), which has been shown to be highly important for soil fertility—especially amongst sandy soils—and could be a factor contributing to the high level of biomass in the NH ecosystem (Yuan et. al, 1967).

Base saturation of soil is related to CEC and is also influenced by parent material, as was reflected in the findings of this study (Fisher, 2000). Base saturation is a measure of the amount of exchange sites already occupied by cations, and aids in buffering soil against acidity (Brady and Weil, 2002; Zak, 2010). This is consistent with the findings that base saturation of the OH ecosystem (99.8 percent) was higher than that of the NH ecosystem (60.53 percent), given that the OH ecosystem has calcareous parent material, a less-acidic pH, and higher OM content.

Biological Properties

Despite the shortened growing season and sandier soils of the NH site, the NH ecosystem was found to contain higher amounts of ecosystem biomass and nitrogen in aboveground (249.628 Mg C/ha and 635.458 kg N/ha respectively), forest floor (12.64 Mg C/ha and 112.492 kg N/ha respectively), and belowground pools (43.979 Mg C/ha and 2498.8 kg N/ha respectively) when compared to the OH ecosystem (121 Mg C/ha and 254 kg N/ha aboveground, 7.83 Mg C/ha and 40.836 kg N/ha forest floor, and 72.669 Mg C/ha and 1294.2 kg N/ha belowground). The physical and chemical properties discussed above—as influenced by climate and physiography—are also directly linked to the ability for the NH ecosystem to support vegetation that is similar to the OH ecosystem. The increased available water content and nutrient retention in the soil of the NH ecosystem due to microclimates, reduced evapo-transpiration, and infrequent disturbance, and the higher rates of evaporation and percentage of coarse fragments within the OH ecosystem are contributing factors. More water allows for more nutrient retention, and more nutrients retained in the soil allow for more plant growth (Zak, 2010).

Higher content of water in soil—as shaped by climate and physiography—also creates an environment that is conducive to microbial presence (Paul, 2007), which is why the NH ecosystem also had a higher level of microbial biomass compared to the OH ecosystem. The OH ecosystem is also a less hospitable environment for microbial presence because the rolling kettle and kame topography limits field capacity in areas due to increased sun exposure and evaporation (Zak, 2010). Coinciding with the larger presence of microbial biomass in the NH ecosystem, there was also a higher rate of nitrification at the NH site (0.178 g $N/d/m^2$ compared to 0.081 g $N/d/m^2$), which also contributed to greater plant growth in that ecosystem. These higher nitrification rates in the NH ecosystem could also be attributed to the relatively younger age of the trees, since nitrification rates decline with increasing stand age (Idol et al., 2003). It would also be assumed that with the higher rate of microbial biomass present in the NH ecosystem, that the microbial respiration rate would also be higher (Cole, 1981). Analyses concluded, however, that respiration rates were lower in the NH ecosystem (24.896 mg C/g/d) than in the OH ecosystem (51.742 mg C/g/d), which can be attributed to variations amongst microbial species present at each of the sites (Fisher, 2000; Paul, 2007).

CONCLUSION

Forest ecosystems are inherently complex, comprised of a multitude of factors that contribute to the formation of physical, chemical, and biological properties and processes (Christopherson, 2009; Schoenholtz, 2000)**.** Understanding the intricate nature of a forest ecosystem necessitates an equally comprehensive analysis of the components which contribute to that ecosystem's existence, and must start with the soil—the foundation of ecosystems (Zak, 2010). This study specifically investigates the physical, chemical, and biological properties of soil within an oak-hickory (OH) and northern hardwood (NH) ecosystem, and analyzes on how factors such as climate and physiography influence soil formation, and subsequently, overall forest ecosystem structure, processes, and productivity.

Despite the differences in latitude, elevation, proximity to bodies of water, landform, and parent material between the OH and NH sites, both ecosystems were found to support relatively similar vegetative communities. Given the sandier soil content and shorter growing season in the NH ecosystem, it would be assumed that the overall productivity of the NH site would be less than that of the OH. However, the NH ecosystem experiences lower levels of evapo-transpiration—and subsequently less water and nutrient loss—due to the microclimates created from its rolling topography. The OH ecosystem consists of a loamy sand soil with lower acidity and a measureable clay and soil organic matter content. Vegetative growth is also affected on this site, however, due to the high percentage of coarse fragments in the soil and the more drastic topographical undulations resulting in microclimates with high rates of runoff and evaporation, and therefore lower rates of nutrient retention. It is the combination of such climatic and physiographical factors that mediate the physical, chemical, and biological processes within the NH and OH ecosystem, helping to shape the ecosystem. These findings support the importance of climate and physiography as key factors that influence soil formation, vegetative composition, and overall ecosystem structure and productivity (Pastor and Post, 1988), and illustrate the extent to which local forest ecosystems could be altered in the face of future climate and landform alterations.

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APPENDIX I

Stinchfield Woods – Oak-hickory Ecosystem:
Soil Profile Description

Stinchfield Woods is an Oak-Hickory ecosystem dominated by *Quercus rubra*, *Quercus alba*, *Carya ovata*, *Carya glabra*, and *Ulmus americana* in the overstory. The site is located on a middle Northeast-facing (78%) slope of a kame. The soil is well drained and is developed in fine ice contact material with sandy loam in the upper horizon, sandy clay loam in the mid-horizons and loamy sand in the bottom horizon.

$O_{i, e, a}$ 3-0 cm; intact and slightly to highly decomposed *Quercus rubra, Quercus alba*, *Carya ovata*, *Carya glabra, Acer saccharum*, and *Ulmus americana* leaves and and fruit; abrupt, smooth boundary.

A 0-8 cm; very dark grayish brown (10YR 3/2) sandy loam; moderate fine subangular blocky structure; 1% gravel; neutral; clear smooth boundary.

E 8-52.2 cm; yellowish brown (10YR 5/6) sandy clay loam; fine granular weak structure; 80% gravel; medium acid; smooth clear boundary.

B_t 52.2-96.8 cm; yellowish brown (10YR 5/4) sandy clay loam; fine granular weak structure; 90% gravel; neutral to alkaline; smooth clear boundary.

C 96.8 cm; brown (10YR 5/3) loamy sand; fine granular weak structure; 80% gravel; alkaline.

APPENDIX II

Manistee National Forest – Northern Hardwoods Ecosystem:
Soil Profile Description

Site 1 of the Northern Michigan fieldtrip is a Northern Hardwood ecosystem dominated by *Acer saccharum*, *Tilia americana*, *Quercus rubra*, *Tsuga canadensis*, *Fagus grandifolia* in the overstory. The site is located on a lower Northwest-facing (33%) slope of a recessional moraine. The soil is well drained and is developed in pre-sorted till with loamy sand and sand in the upper horizon, sandy loam and loamy sand in the mid-horizons and sand in the bottom horizon.

$O_{i, e, a}$ 5-0 cm; intact and slightly to highly decomposed *Quercus rubra, Acer saccharum*, *Tsuga Canadensis, and Fagus gradifolia* leaves and fruit, abrupt smooth boundary. Special feature: Very generous.

A 0-10 cm; very dark brown (10YR 2/2) loamy sand; fine granular weak structure; 0% gravel; very slightly acid; clear wavy boundary.

E 10-22 cm; dark yellowish brown (10YR 3/6) sand; fine granular weak structure; 0% gravel; neutral to very slightly acid; clear smooth boundary.

$B_{h, s}$ 22-43 cm; dark reddish brown (5YR 3/4) sandy loam; medium granular weak structure; 0% gravel; neutral; clear smooth boundary.

B_s 43-110 cm; dark yellowish brown (10YR 4/6) loamy sand; medium subangular weak structure; 0% gravel; very slightly acid; clear smooth boundary.

C 110 cm; brownish yellow (10YR 6/6) sand; fine granular weak structure; 0% gravel; neutral.