SOIL-SITE FACTORS ASSOCIATED WITH ECOLOGICAL LAND TYPES IN NORTHEASTERN WISCONSIN AND THEIR INFLUENCE ON SURVIVAL AND GROWTH OF RED PINE (PINUS RESINOSA AIT.) SEEDLINGS ON HARDWOOD CONVERSION SITES

by

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Abstract

Hardwood conversion to red pine (*Pinus resinosa* Ait.) is actively being conducted on the Padus, Pence, and Vilas Ecological Land Types (ELT's) in northeastern Wisconsin. Before clearcutting, 10 plots were located on each ELT and selected soil-site characteristics were sampled. Discriminant analysis showed that some of these characteristics were effective in discriminating between the three ELT's. The "U" or "jackknife" method of error estimation produced correct classifications of 83.3%, 66.7%, 56.7%, and 41.2% for the following data sets: soil and understory vegetation variables, soil variables only, understory vegetation variables only, and post-cut understory vegetation variables, respectively. In the spring after clearcutting each of the 30 plots were planted with 20 2-0 bare root red pine seedlings. After one growing season there were no significant differences in seedling survival or average height growth on the three ELT's. Average diameter growth on the Vilas was significantly higher when compared with the Pence, and the Padus was intermediate. The level of competing vegetation was evaluated at the end of the first growing season and no significant differences were found at that time. On a six plot subsample, seedling characteristics (diameter, height, and needle water tension) and site characteristics (soil water tension, soil temperature, total soil nitrogen, and ammonium and nitrate concentrations) were measured on July 3, 7, 30, and August 13, 1985. Multivariate analysis of variance on a repeated measures design showed that first year seedling growth parameters were significant with respect to time but not ELT. Analysis of seedling water tension and site characteristics showed that the sandiest soil (Vilas) had the poorest water relations and lowest nitrogen levels, but this was not reflected in first year growth. This study has shown that there were soil-site differences between the Padus, Pence, and Vilas ELT's, but that one growing season was not sufficient time to produce clear differences in seedling survival, growth, or the level of competing vegetation.

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INTRODUCTION

Portions of northern Wisconsin were originally covered with stands of white pine (*Pinus strobus* L.) and red pine (*Pinus resinosa* Ait.) (Wilde et al. 1964). By the early 1900's the pine forests had been cut, and today the predominant forest types are northern hardwoods and aspen (*Populus tremuloides* Michx.). In order to meet the demand for softwood fiber, 155,200,000 cu. ft. were imported in 1977 from other states and Canada (Lindberg and Hovind 1983). Softwood demand is the primary reason that both public and private forestry organizations are converting some of the hardwood stands to softwoods, with the predominant species being red pine. Analysis of plantations that were established in the 1930's and 1940's have shown that red pine can greatly outproduce hardwoods in the Lake States.

Considering the regional significance of hardwood conversion to red pine, surprisingly little research has been done in this area. Problems exist in identifying sites that are best managed in hardwoods versus sites that should be converted to pine. In a conversion program the following questions are often unanswered:

- which sites should be converted
- which sites will be hard to convert and why
- will the competing vegetation be difficult to control on one site but not on another
- how the red pine seedlings survive and grow in the different levels and types of competition
- how different soil types affect seedling survival and growth

These are all questions that require more investigation. It is the goal of this research project to provide information useful to land managers faced with these problems and researchers looking at the many aspects of site conversion.

OBJECTIVES

In northern Wisconsin, conversion of hardwood sites to red pine is actively being conducted on three Ecological Land Types (ELT's), Stambaugh-Padus, Pence, and Vilas. The objectives of this study are to:

1. Determine if there is a significant difference in soil-site characteristics between the three ELT's.
2. Evaluate the level of competing vegetation on the three ELT's.
3. Determine if there is a significant difference in red pine seedling survival and growth on the three ELT's.
4. Evaluate how the three ELT's differ in site factors associated with red pine seedling survival and growth.

LITERATURE REVIEW

Forest Site Quality Classification

Increasing world population has resulted in a decreasing forest land base coupled with greater demand for forest products. In order to provide more products on less land, intensive management is needed on the most productive land. Simply stated, larger trees of better quality can be grown in shorter rotations (Carmean 1975). Classifying forest land into different levels of productivity is critical in achieving optimal levels of management.

Forest classification can involve any one of several systems, or any degree of integration of these systems. The goal is to group tracts of land into similar management units. No one system is automatically better than another. The application of a forest classification system should depend on clearly stated objectives (Pierpoint 1984, Rowe 1962), and consist of a level of complexity appropriate to the needs of the forest manager.

Forest Cover Type

Rowe (1984) stated that

> In the early days of forestry attention was narrowly focused on forest cover types and their delineation. Foresters were stand-centered rather than land-centered, so a taxonomy of stands based on vegetation served very well.

This attitude prevailed because there were extensive tracts of forested land. Forest cover type (also known as timber type) is still widely used for identifying and mapping stands today (Eyre 1980). It is very easily obtained from aerial photos and informs the forester of the species, size, and density of the current stand. A major problem is that it only conveys information about the current stand (Westveld 1951). There is no information concerning stand history, successional trends, soils, or whether the stand is growing under marginal or optimal conditions (Daubenmire 1973). In addition to these limitations a forest cover map is very temporal (Coile 1938). Any changes brought about by time, disease, insects or man will make these maps obsolete. Despite these limitations a forester has to know what the current forest cover is and with the ease of aerial photos this system is not likely to disappear in the near future.

Site Index

Site index is the most common way of estimating the quality of a forest site (Ralston 1964, Jones 1969, and Carmean 1975). It is also the standard for comparing other classifications of site quality. Site index is defined as the average height of dominant, or dominant and codominant trees at some arbitrarily chosen base age (Jones 1969, Pritchett 1979, and Spurr and Barnes 1980). Because stand height is often considered somewhat independent of stand density (Jones 1969, Carmean 1975, and Spurr and Barnes 1980), height at a base age provides a good indicator of the quality of the site. Site index provides a quantitative variable that is commonly used in yield regressions to indicate different levels of forest productivity on different quality sites (Jones 1969, Carmean 1975, and Pritchett 1979). The range of site index for a species is most commonly expressed by a series of polymorphic curves which are based on regionally-derived stem analysis data (Carmean 1975 and Pritchett 1979).

Some of the problems associated with the use of site index are as follows:

-it assumes that a stand will have the same site index throughout the life of that stand (Jones 1969, Spurr and Barnes 1980).

-it requires the presence of undamaged, even-aged, dominant, or dominant and codominant trees of the desired species (Jones 1969, Daubenmire 1976, and Monserud 1984).

-differences in juvenile growth caused by factors such as brush competition, animals, insects, and disease can affect site index and are not related to site quality (Carmean 1975, Daubenmire 1976, and Spurr and Barnes 1980).

-site index does not reflect the best type of management or response to silvicultural treatment (Jones 1969, Daubenmire 1976, and Pritchett 1979).

-silvicultural practices such as thinning may change the average height (Spurr and Barnes 1980).

-subjective tree selection (Spurr and Barnes 1980).

-it is not always easy or possible to obtain accurate measurements of tree height and/or age (Spurr and Barnes 1980).

Despite numerous limitations, site index can be quickly determined and applied in forest classification. A common practice used in the Pacific Northwest is to divide the range of site indexes into five site classes, with 1 representing the most productive site class and 5 representing the least productive site class (McArdle et al. 1961). Site class information is usually provided on a stand basis and used to compare the relative productivity of forest stands.

Growth intercept is a method of estimating site index for young stands. This has been studied in red pine by Bull (1931), Ferree et al. (1958), Day et al. (1960), Wilde (1964), and Alban (1972a, 1979).

Vegetative Indicators

Daubenmire (1961) defined a habitat type as

> all the area that supports, or is capable of supporting, the same kind of climax vegetation in the absence of disturbance by fire, logging, heavy grazing, etc.

The occurrence and/or abundance of key indicator plants is used to identify habitat types. The use of indicator plants to classify forest sites is not a new concept. This system has been widely used in Finland since Cajander (1926) first published The Theory of Forest Types. This type of classification system received limited attention in the United States (Coile 1938, and Westveld 1951, 1952, 1954) until the 1960's when Rexford Daubenmire started classifying forest habitats in eastern Washington and Idaho (Kotar 1984). Habitat type classifications have been developed and are widely used in North America (Daubenmire and Daubenmire 1968, Layser 1974, Paysen et al. 1980, Steele et al 1981, Steele et al. 1983, Hanks et al. 1983, Hoffman and Alexander 1983, Coffman et al. 1983, Alexander et al. 1984a 1984b, Mauk and Henderson 1984, Alexander 1985, and Youngblood and Mauk 1985).

The vegetative indicator system does not identify the current forest type, but uses key understory species to identify the climax vegetative associations. Kotar and Coffman (1982) explained that different tree species occur as successional communities in a variety of environmental conditions, and thus have a broad ecological amplitude. Therefore, they convey very little information about the site quality and only reflect the successional stage of the stand. However, the occurrence, abundance, and/or proper combination of understory species can reflect important differences in site quality if the understory species have a very narrow ecological amplitude.

Pregitzer and Barnes (1982) studied the effectiveness of ground flora to indicate specific soil conditions in the McCormick Experimental Forest, upper Michigan. They found species indicator groups present that were sensitive indicators of soil drainage, soil texture, soil pH, and soil total nitrogen. Soil mottling in the 0-38 cm range was present for 92% of the Osmunda group occurrence. The Vaccinium group indicated soils with more than 90% total sand. The authors developed a pH gradient indicated by species groups that was significant at the 10% level. Presence of the Viola group indicated a significantly higher level of total nitrogen. This study demonstrated that indicator groups can be used as phytometers of edaphic factors.

Kotar and Coffman (1982), and Daubenmire (1980) discussed the potential for using understory species in any of several successional stages to predict the climax association. The understory species have adapted to a closed canopy. After disturbance, sun-requiring herbs invade the site but the indicator species will not disappear because they are perennial plants that grow back from bulbs, corms, caudexes, or rhizomes. With the establishment of a seral forest and the resulting crown closure, the sun-requiring plants will die out and the previous understory species will persist indefinitely.

Hodgkins (1968) evaluated the use of plant indicators to estimate the productivity of longleaf pine in Alabama. He found that a plant indicator scale could accurately predict site quality. In addition, a comparison of logged and unlogged areas was conducted. Results showed an "astonishing stability" of indicator species after logging disturbance.

Daubenmire (1976) stated that

> Natural vegetation reflects the algebraic sum of all environmental factors important to plants.

Since foresters classify sites with respect to quality for producing wood fiber, the use of plants as a phytometer of the total environmental factors that influence tree growth seems reasonable. Plant indicators do not provide information about the physical factors responsible for growth, but they do reflect the ability or lack of it to provide for tree growth (Daubenmire 1976). A habitat classification by itself does not reveal productivity or responses to disturbance; however, this can be determined directly by field tests (Coffman et al. 1983).

Coffman and Hall (1976) investigated the association between habitat types and red pine plantation productivity. They compared red pine plantations growing on the Tsuga-Maianthemum (TM) and Pinus-Maianthemum-Vaccinium (PMV) habitat types in northern Michigan. Site index differed significantly (0.01 level) between the TM and PMV types (Figure 1). Total pulpwood production was similar on the two types until 15 to 20 years, but by 38 years the TM type had over 500 cu m/ha and the PMV type had only 240 cu m/ha (Figure 2). Basal area comparisons between the two types were similar (Figure 3). With the absence of supporting data, the authors suggested that the differences are caused by different water holding

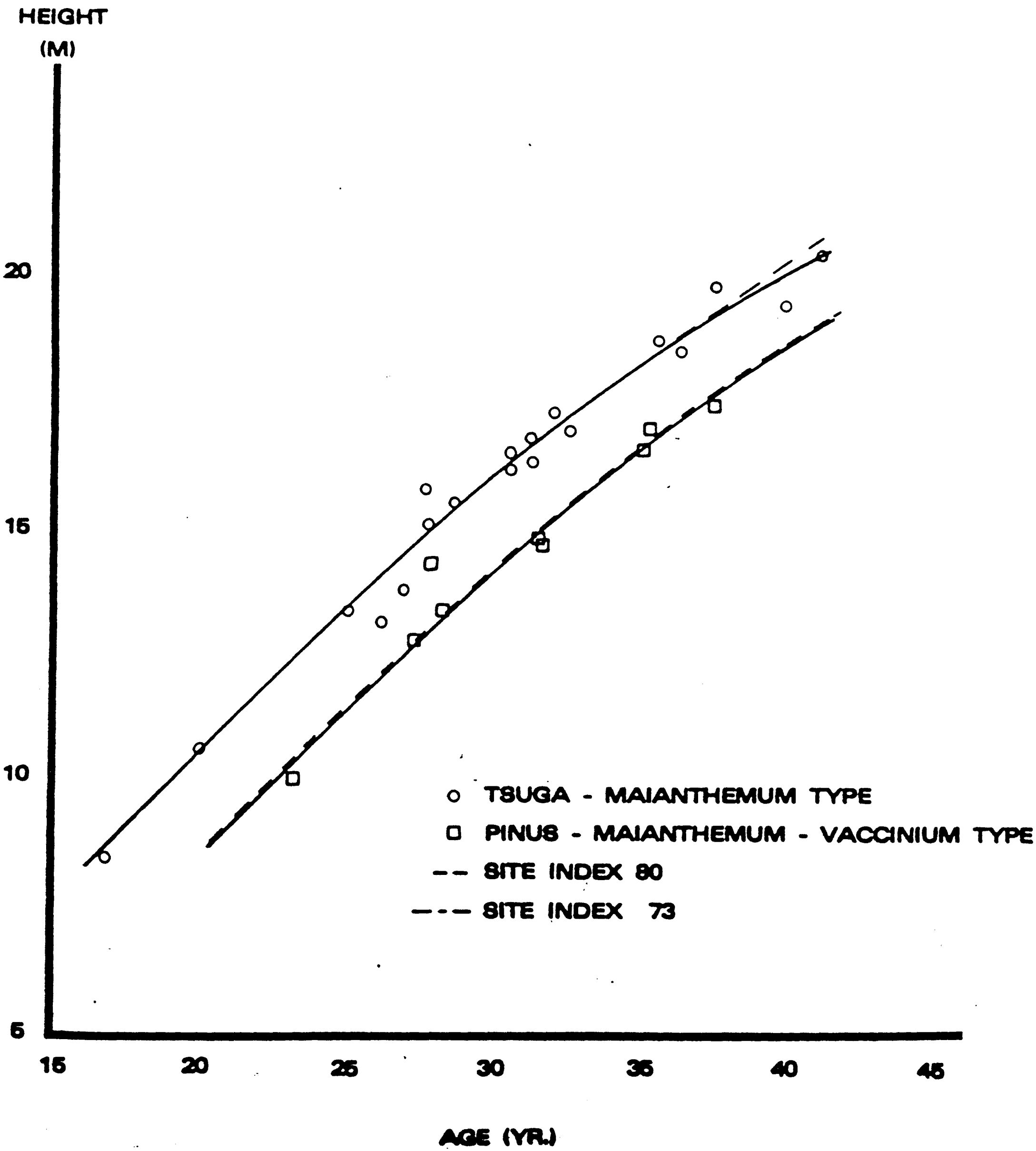


Figure 1. Height/age curves for dominant or codominant trees growing on two habitat types as related to red pine site index curves developed by Gevorkiantz (1959) and interpolated for S.I. 80 and 73 (Base age 50 years) (Coffman and Hall 1976).

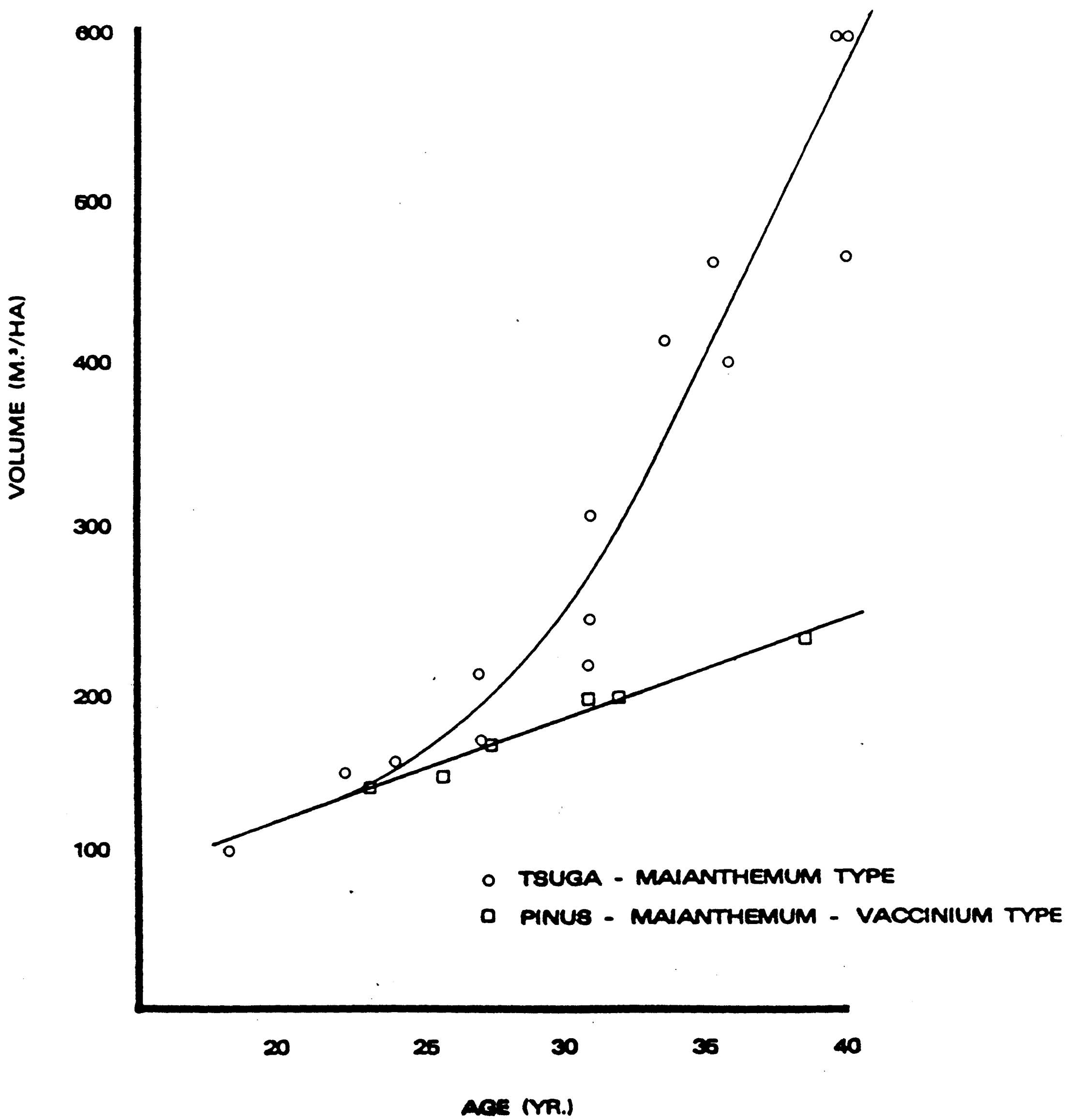


Figure 2. Total pulpwood production by age for fully stocked red pine plantations growing on two habitat types (Coffman and Hall 1976).

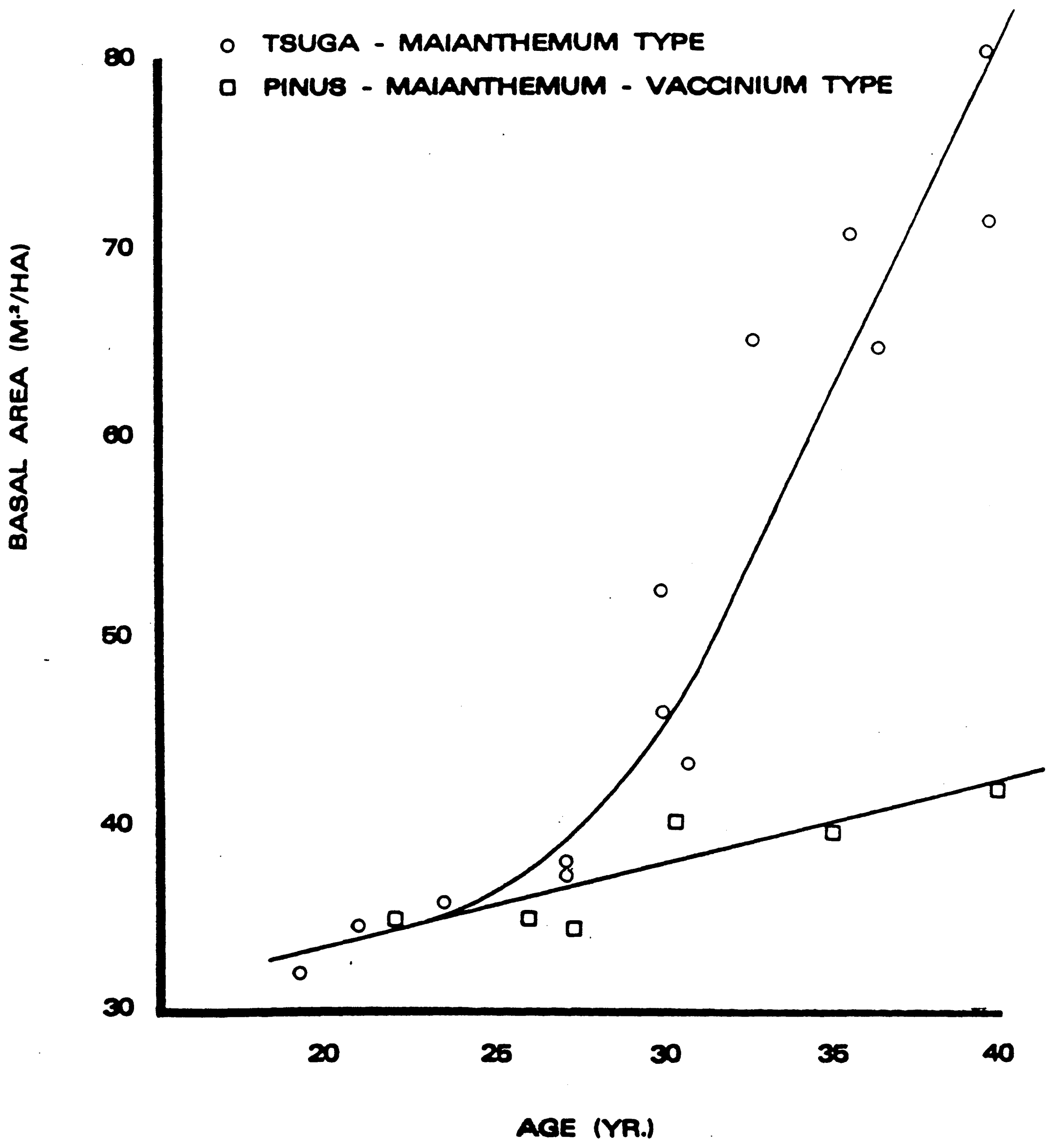


Figure 3. Total basal area growth by age for fully stocked red pine plantations growing on two habitat types (Coffman and Hall 1976).

capacities and nutrient relationships between the soils associated with the two habitat types. The PMV type occurs on sandier soils and moisture is probably depleted early in the growing season. The TM type occurs on loamier soils that retain moisture longer into the growing season. The authors stressed that this needs to be confirmed with further investigation.

Coffman et al. (1983) cautioned the user of their field guide that the second phase of development i.e., determining descriptive or interpretative information, is only beginning. After a habitat classification system has been developed for an area it is imperative that research continue to relate the habitat types to productivity for a variety of species, soils, landforms, wildlife and regeneration problems. If this supportive research is provided, habitat classification can be a very valuable tool for a variety of disciplines.

Soils

The early emphasis in soil mapping was to map primarily agricultural areas. Forest land received only superficial attention. Recently forested areas have been actively mapped and this provides a valuable inventory for the forester (Carmean 1975).

A major problem with soil surveys is the large amount of variability of site productivity within each mapping unit (Carmean 1961, Ralston 1964, Farnsworth and Leaf 1963, Van Lear and Hosner 1967, Craul 1968, Watt and Newhouse 1973, Carmean 1975, and Grigal 1984). Some of the variation is due to soil and topographic variation that is not accounted for in the mapping units. Soil units based on soil taxonomy (Soil Survey Staff 1975) have also shown a similar degree of variation (Harding 1982). Numerous soil-site studies, however, have identified soil and topographic features that are correlated to tree growth (Carmean 1975). The primary studies involving red pine are discussed in the next section of this literature review.

Site index is the most common means of associating site quality with mapping units. The problems with using regional site index curves has already been discussed. When soils are mapped, frequently few trees are measured to determine the relative site index of that mapping unit. The result is generally very poor correlation between mapping units and site quality (Grigal 1984).

Grigal (1984) attributed part of the problem to the quality of the work done in the field. In many cases unrealistic production goals were established for field soil mappers. These production goals were established on relatively flat and open agricultural lands. In inaccessible, rough, and forested land it is usually quality that is sacrificed to maintain the production quantity.

Grigal (1984) recommended changing the scale of soil survey maps as follows:

> Forest land managers are sophisticated map users. If presented a map at 1:50,000 scale, they will treat it with the degree of uncertainty that it merits. However, when presented with a map at a scale near their standard 1:15,840, they will not allow it to be endowed with uncertainty. As a result the survey falls victim to the quality-quantity problem, leading to loss in credibility.

To properly manage the forest resource it is very important to have accurate information on the soils within a management area. Currently there are many problems with the soil surveys of forested areas. There has been an increase in dialogue between foresters and soil mappers within the past several years and with cooperation soil surveys will become a powerful tool in determining site quality and making management recommendations.

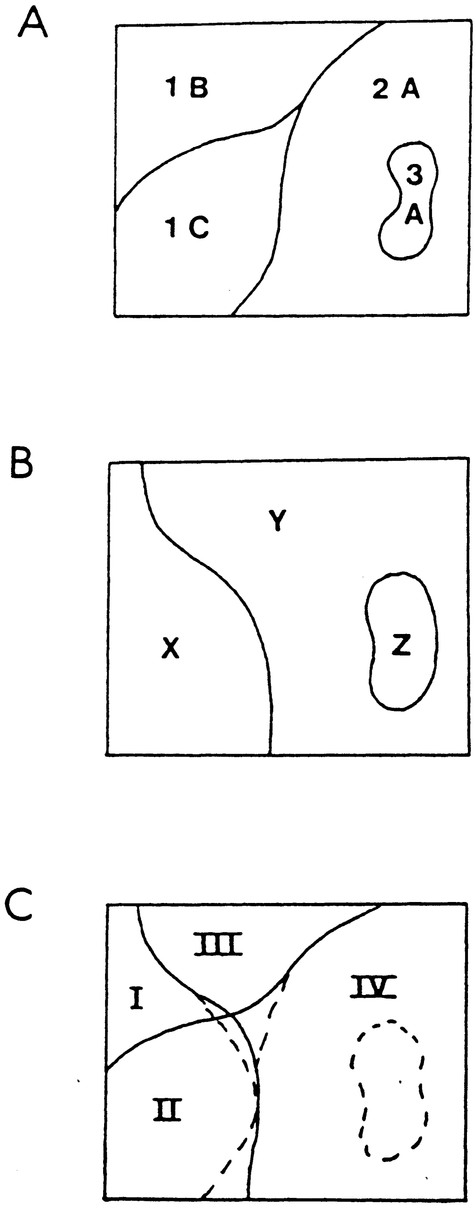
Ecological Classification Systems

The methods that have been presented are often combined into an integrated system that meets the objectives of the manager. When developing a system these objectives should be clearly stated and the system evaluated with respect to the objectives before implementation. If this is not accomplished first, the re-mapping can be very expensive or superimposing one classification system on another can provide poor results (Daubenmire 1973).

An integrated system can be as simple as including a designation for the current forest cover type when mapping habitat types (Daubenmire 1973), or as complex as including many multiple levels such as forest region, landforms, soils, and habitat types (USDA 1971).

Different factors can be combined into multi-factor units that provide a better expression of site quality than either factor alone. Pregitzer and Barnes (1984) used discriminant analysis to evaluate a field classification system that identifies eleven ecosystem units in the McCormick Experimental Forest, upper Michigan. When they used soil and topographic parameters to predict site unit membership there was 24% misclassification. Vegetation alone misclassified site unit membership by 37%. When soil, topography and vegetation were used the result was 19% misclassification. There was an efficiency increase of 18% over vegetation alone and 5% over soil and topography. For this study area in upper Michigan, the simultaneous use of soil, topography and vegetation was the most effective way of distinguishing ecological units.

Arnold (1984) stated that a vegetation type does not necessarily correspond to a single soil type and vice versa. Soil mapping and vegetation mapping can be combined to provide information about the association of the two classification systems. Figure 4 shows schematic maps of the same area for soils (A) and vegetation (B).



SOIL LEGEND

1B Soil 1, 2-5% slopes
1C Soil 1, 5-10% slopes
2A Soil 2, 0-2% slopes
3A Soil 3, 0-2% slopes

VEGETATION LEGEND

X X association, open canopy forest
Y Y association, closed canopy forest
Z Z association, shrub cover

ECOLOGICAL RESPONSE UNIT LEGEND

I 1B/X
II 1C/X
III 1B/Y
IV 2A/Y

Areas to be included

Figure 4. Schematic maps of soils, vegetation, and ecological response units for the same area (Arnold 1984).

When these two maps are combined, the percent association of vegetation by soils (Table 1A) and percentage of soils by vegetation (Table 1B) can be used to develop multi-factor units. This type of system can be used to identify "ecological response units" (Figure 4C). These soil/vegetation units will respond similarly to management activities.

Many of the National Forests throughout Region 9 are in various stages of developing an integrated ecological classification system. The system developed for the Nicolet National Forest used information from the most recent forest soil resource inventory and the Lake States habitat classification system developed by Coffman et al. (1983). This system classifies groups of soil series and the corresponding vegetative habitat types that will respond similarly to management activities. These units, or Ecological Land Types (ELT's) are named for the primary soil in the association. A variety of productivity and interpretation-related information has been developed for each ELT. The ELT, therefore, has become the basic unit of mapping and also the primary management unit.

Table 1. Percentage distribution of vegetation by soils (A) and percentage distribution of soil by vegetation (B) (Arnold 1984).

A.	Vegetation Association		
Soil	X	Y	Z
1B	30	70	0
1C	84	16	0
2A	2	89	9
3A	0	0	100

B.	Soil Map Unit			
Vegetation Association	1B	1C	2A	3A
X	27	70	3	0
Y	29	7	64	0
Z	0	0	50	50

Soil-Site Studies For Red Pine

As previously discussed, a major concern of foresters is assessing the productivity of a site. The following approaches are often taken to make this assessment:

-use of mensurational techniques to directly measure fiber production (Husch et al. 1982)

-use of site index as an indirect measure of site quality

-use of vegetative indicators as a broad index of relative productivity

All of these approaches require the presence of tree or plant specimens suitable for the appropriate measurements. If the site has recently been disturbed, or currently contains species that are not the species of interest, an evaluation of the soil resource is a useful indirect way of estimating the potential productivity.

Soil-site evaluation involves the measurement of soil and topographic parameters followed by the development of a regression equation which predicts the productivity of the site, as measured by some appropriate dependent variable such as site index (Carmean 1975). Carmean (1975) presented a summary of soil-site studies that show a strong relationship between soil features and site index. The soil features that show a high correlation with red pine growth are texture, nutrient content, depth and occurrence of fine-textured bands, and depth of A plus B horizons (Wilde et al. 1964, Wilde et al. 1965, and Hannah 1969).

Red pine once occurred on sandy soils throughout the Lake States region. Extensive exploitation, followed by fires and farming, have fragmented and changed the red pine stands and the soils upon which they are located (Wilde et al. 1964). Reforestation has produced stands on a wide variety of soils and with a wide range of productivity. A major emphasis of the soil-site research has been to quantify the productivity of plantations and natural stands on a variety of soil textures.

Van Eck and Whiteside (1958) found that soil texture and drainage is closely related to site quality, (Tables 2 and 3). Well drained sandy loam, loamy sand, and sandy soils were found to have the highest site index. An increase in fineness of texture beyond the sandy loam class resulted in a decrease in site index, which is in turn related to a decrease in spodic horizon development. Soil texture reflects the water holding capacity of a soil and its aeration. Van Eck and Whiteside's work

Table 2. Soil series on which red pine plantations were studied and their interrelationships to primary materials and natural drainage conditions (Van Eck and Whiteside 1958).

Relative texture of primary material	2 storied primary material	1 storied primary material	
	Well drained a	Well drained a	Imperf. drained b
1.5 (clay loams)		**Morley(a)**	
2.5 (loams)		**Miami(a)** **(b)Thackeray**	
3 (sandy loam)	3/2 **Kendollville(a)** 3/g **Fox(a)** **Newaygo**	McBride **Hillsdale** **Oshtemo**	
4 (loamy sand)	4/2 Menominee	Boyer Montcalm Rousseau Mancelona Leelanau	Wainola
5.0 (sand)	5/2 Melita	East Lake Kalkaska Wallace(a)	
5.3 (sand)		Rubicon Graycalm(c) Spartan	
5.7 (sand)		(b)Croswell Grayling	Au Gres

(a) A separate set of more curved site index curves was used for these soils than for the other series. The series in bold type are Gray-Brown Podzolic soils.

(b) Moderatly well drained soils. The Croswell and Au Gres series may occur in any of the deep sand catenas but the ones investigated in this study were associated with the Grayling series. The Croswell series is commonly placed in the 5.0a group and the Au Gres series in the 5.b group.

(c) Graycalm has a minimal Podzol or Brown Podzolic upper sequum but thin textural B horizons occur in the profile.

Table 3. Average site indices of red pine plantations studied on different soils in Table 2 (Van Eck and Whiteside 1958).

Relative texture of primary material	2 storied primary material	1 storied primary material	
	Well drained a	Well drained a	Imperf. drained b
1.5 (clay loams)		45.0(1)	
2.5 (loams)		58.3(1) (b)61.9(1)	
3 (sandy loam)	47.0(2) 55.0(1) 52.1(2)	61.5(1) 64.9(1) 69.2(4)	
4 (loamy sand)	74.1(2)	65.9(1) 60.6(16) 62.6(5) 62.5(10) 57.5(3)	58.1(2)
5.0 (sand)	73.6(2)	61.8(2) 63.0(7) 58.0(2)	
5.3 (sand)		58.3(23) 56.0(10) 55.1(2)	
5.7 (sand)		(b)55.0(2) 35.8(14)	46.5(2)

indicated that the lower site indices on the finer-textured soils were associated with more runoff losses and probably poorer aeration. The Grayling sand (site index 35.8) and the Rousseau fine sand (site index 62.6) had very different water holding capacities, 3.97 inches and 9.64 inches, respectively. The particle size analysis (Table 4) of both soils revealed major differences in the sand fractions throughout both profiles. A higher percentage of finer sand results in better water holding capacity without sacrificing soil aeration. The loamy sand soils provided the best combination of aeration and water holding capacity for red pine production.

Stone et al. (1958) showed a close association between site index and soil drainage class, (Figure 5). Regression analysis showed that, within this study sample, 79% of the variation in the site index was accounted for by drainage class alone. Soil drainage class, texture, and aeration were all closely related. Soil drainage also affected the occurrence of root lesions, (Figure 6). This was an indicator of the overall health of the root system, which in turn will affect long-term growth. Stone et al. found that red pine is best suited for well-drained and well-aerated soils.

Table 4. Mechanical analyses of Grayling sand and Rousseau fine sand (as percentages of material < 2 mm, ovendry basis)(Van Eck and Whiteside 1958).

Horizon	Depth inches	Fraction: Fine gravel 2-1 mm	Coarse sand 1-.5 mm	Medium sand .5-.25 mm	Fine sand .25-.10 mm	Very fine sand .10-.05 mm	Silt + clay <.05 mm
GRAYLING SAND							
A1	0-3	1.3	39.9	38.6	14.3	2.9	2.9
B21	3-6	1.7	48.6	36.2	10.9	1.2	1.3
B22	6-18	6.6	33.3	38.1	21.1	.5	.3
C1	18-30	2.6	63.8	26.5	6.7	.3	.1
C2	30-120	.5	34.8	51.8	12.1	.6	.1
ROUSSEAU FINE SAND							
A1,A2	0-3	.2	6.8	31.3	50.1	10.2	1.4
B22	3-10	.2	6.5	29.0	50.9	10.5	2.9
B3	10-22	.2	6.3	29.9	52.6	9.6	1.3
C1	22-46	.0	1.3	22.0	67.0	8.8	1.0
C2	46-90	.0	.1	1.9	55.3	37.2	5.5
C3	90-150	.0	1.0	2.1	67.5	27.2	2.1

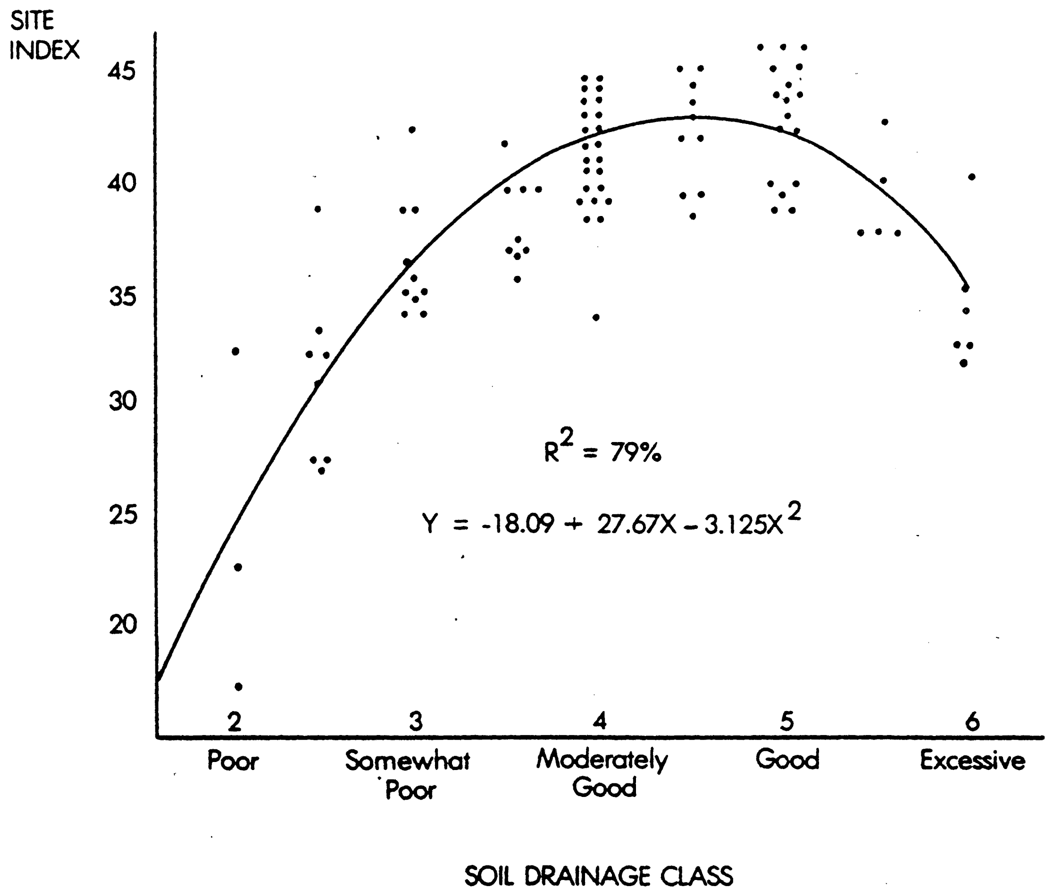


Figure 5. Red pine: Site index versus soil drainage (Stone et al. 1958).

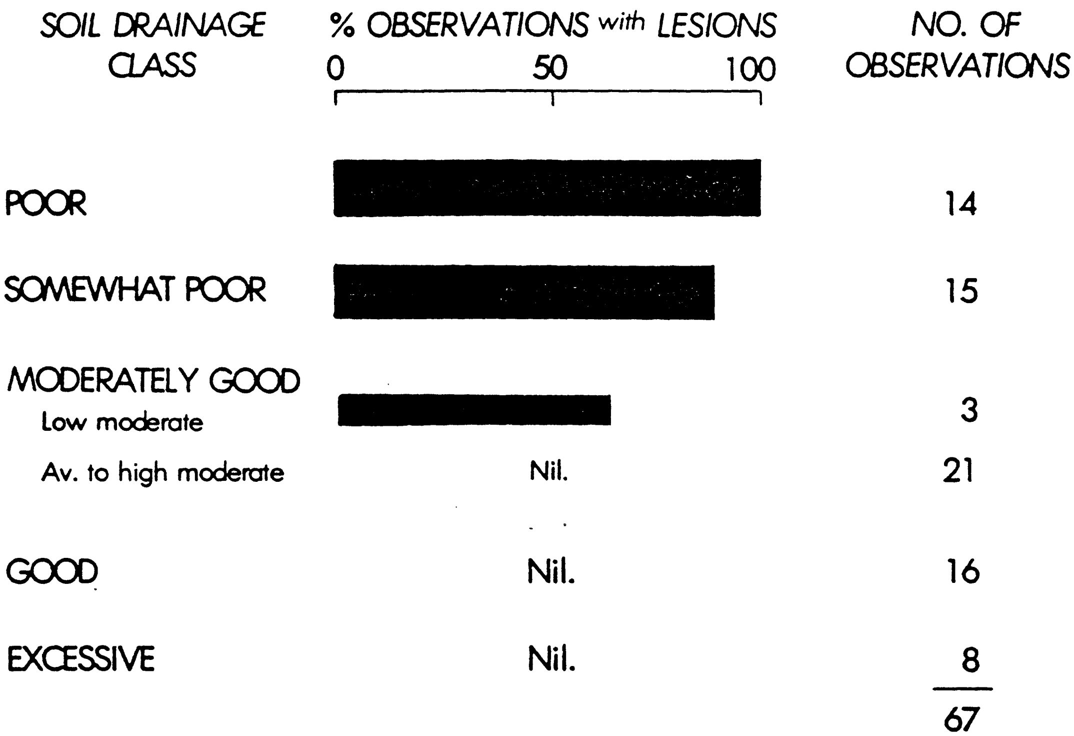


Figure 6. Red pine root lesions and soil drainage (Stone et al. 1958).

Wilde et al. (1965) investigated the affect of soil texture on height growth patterns in red pine plantations in Wisconsin. They used an H/I ratio, (H is the height over age and I is the average five year nodal growth above breast height). This ratio showed changes in growth patterns with varying soil conditions. Plantations on sandy soils were reasonably free of weed competition and showed a rapid early growth, but as the crowns closed there was increased competition for limited nutrients and water. As a result, these plantations often showed a fractional H/I ratio. Wilde et al. (1964) showed that heavy soils (20% silt plus clay) produced average height increments of 16 inches per year compared to sandy soils with an average of 20 inches per year. This was attributed to the reduction of aerobic conditions in fine textured soils. Alban and Prettyman (1984) found that the site index curves developed by Gevorkiantz (1957) accurately depicted red pine height growth on fine-textured soils.

Wilde et al. (1964) studied the relationship between growth of red pine and soil fertility on non-phreatic sandy soils in Wisconsin. Three site quality groups were evaluated (Table 5). Low quality sites had a critical deficiency in mineral colloids, organic matter and nutrients. The medium sites had higher fertility levels

Table 5. Average state of fertility of soils supporting red pine plantation having different rates of growth (Wilde et al. 1964).

Height growth Class	Average volume	Reaction	Silt plus sand	Organic matter	Exchange capacity	Total N	Avail. P	Avail. K	Exch. Ca	Exch. Mg
inches/ yr	cu ft/ yr	pH	%	%	me/100g	%	lbs/A		me/100g	
				Low Site Quality (Site Index 45)						
7-13	26	5.01	7.3	1.20	2.75	.048	18.2	65.3	0.76	0.17
				Medium Site Quality (Site Index 57)						
15-17	57	5.1	8.8	1.31	3.19	.069	26.7	74.6	0.84	0.24
				High Site Quality (Site Index 65)						
18-22	98	5.1	12.2	1.99	4.70	.086	38.6	121.2	1.41	0.33

1 Medians instead of arithmetic averages are given fro all pH values because of the logarithmic nature of this factor.

and the low end of this group had marginal supplies of available phosphorus, potassium and exchangeable magnesium. The high quality sites were deemed free of nutrient deficiencies. The minimum levels of soil fertility presented in Table 6 are based on the low end of the medium site quality group. Regression analysis was used to identify the relationship between height growth and several soil parameters. Available potassium, exchangeable calcium, and exchangeable magnesium were all strongly correlated with organic matter, silt plus clay, and height growth (Table 7). The analysis produced the following regression equation:

$$\text{average annual height growth, inches/yr.} = -10.7 + 2.5(X_1) + 3.5(X_2) + 0.16(X_3) + 0.22(X_4) + 0.01(X_5) \qquad (1)$$

where X_1 = % organic matter, X_2 = pH, X_3 = lbs/ac available phosphorus, X_4 = % silt plus clay, and X_5 = lbs/ac available potassium. If the values from Table 6 are substituted into the equation using a pH of 4.8, the average annual height growth is 16 inches per year.

Table 6. Minimum levels of soil fertility for planting red pine (Wilde et al. 1964).

Reaction (pH)	4.8 - 6.0
Silt plus clay (percent)	9.0
Organic matter (percent)	1.3
Available P (lbs/A)	25.0
Available K (lbs/A)	70.0
Exchangeable Ca (me/100g)	0.80
Exchangeable Mg (me/100g)	0.20

Table 7. Results of multiple correlations with average height growth as dependent variable (Wilde et al. 1964).

Independent variable	Coefficient of simple correlation	Coefficient of partial correlation	R2
Organic matter	0.582 **	----	0.339
Organic matter	0.582 **	0.624 **	0.465
Reaction, pH	0.349 **	0.437 **	0.465
Organic matter	0.582 **	0.535 **	0.538
Reaction, pH	0.349 **	0.439 **	
Available phosphorus	0.504 **	0.369 **	
Organic matter	0.582 **	0.482 **	0.60
Reaction, pH	0.349 **	0.445 **	
Available phosphorus	0.504 **	0.392 **	
Silt and clay content	0.442 **	0.379 **	
Organic matter	0.582 **	0.412 **	0.607
Reaction, pH	0.349 **	0.432 **	
Available phosphorus	0.504 **	0.392 **	
Silt and clay content	0.442 **	0.338 **	
Available potassium	0.465 **	0.085 (n.s.)	

** Significant at the 5 percent level.
n.s. Not significant

Alban (1972b and 1974) demonstrated the importance of phosphorus in red pine site quality in Minnesota. Alban (1974) compared red pine site index to soil properties in the surface soil (0-25 cm.), subsoil (25-100 cm.), total mineral soil (0-100 cm.), and forest floor. Nitrogen and phosphorus in the surface soil were the properties most closely related to site index. On these sandy soils, nitrogen and phosphorus can be limiting factors. Growth responses may be obtained if fertilizer is applied when surface soil phosphorus is less than 80 kg/ha and nitrogen is less than 1200 kg/ha.

Hannah (1969) investigated the relationship between red pine stemwood production and soil features in Michigan plantations. He found that good sites were six times more productive than poor sites when dry weight and volume were used as a measure of productivity. Site index was only three times higher on the good sites compared to the poor sites. This indicates that weight or volume are more sensitive indicators of site quality than site index. The results of stepwise multiple regression analysis showed that with volume and weight as dependent variables, % silt plus clay in the finest textured horizon and depth of the A plus B horizons were the most important factors (Table 8).

Table 8. Soil depth and texture variables tested for correlation with net stemwood weight and volume of red pine at age 35 (Hannah 1969).

	Independent Variables
X1	Percent silt plus clay in the finest textured layer
X2	Depth of total A horizon (A1 plus A2)
X3	Depth to the finest textured horizon
X4	Depth of total A plus B horizons
X5	Interaction (X2*X10)
X6	Percent fine plus very fine sand in the A horizon
X7	Percent fine plus very fine sand in the B horizon
X8	Percent fine plus very fine sand in the C horizon
X9	Average depth in inches to the first texture band
X10	Percent silt plus clay in the B horizon
X11	Maximum percent of fine sand plus very fine sand in the profile
	Dependent Variables
Y1	Net volume at age 35, 1000 cu ft/A
Y2	Net dry weight at age 35, 1000 lbs/A

Prediction Equations

$$Y1 = 0.48 + 0.05\ X1 + 0.28\ X2 - 0.02\ X3 + 0.03\ X4$$

Ave. Y = 3.30   S.E. = ± 1.02 $R^2 = .71$

$$Y2 = 12.49 + 1.02\ X1 + 5.53\ X2 - 0.41\ X3 + 0.71\ X4$$

Ave. Y = 34.15   S.E. = ± 21.72 $R^2 = .69$

Further studies on the importance of fine textured horizons on tree growth were conducted in Michigan by Hannah and Zahner (1970). Tree roots branched and proliferated at the upper surface of textural bands, which are important in providing water and nutrients to growing trees. Site indexes were significantly higher on soils with texture bands as compared to soils without bands. Alban (1974) studied the affect of fine textured layers on red pine site index in Minnesota. Soils with fine texture layers had a site index averaging 18.4m., those without averaged 15.9m.

White and Wood (1958) found that between two portions of the same plantation there was a noticeable difference in growth rates. They examined soil physical and chemical properties. The only difference was in the depth and thickness of the fine textured layer. When the layer was within 6 ft. the stand volume was 2,080 cu. ft./acre. When it was at a depth greater than 6 ft. the volume was only 1,090 cu. ft./acre. They determined that the presence of this layer within the rooting depth provided at least an additional foot of available water storage.

There have been several studies conducted that involved red pine growth on Spodosol soils. In general, the degree of spodic horizon development was found to be important in influencing tree growth. Van Eck and Whiteside (1958) studied the effects of spodic development on red pine site index, and showed a decrease in site index with a decrease in spodic development (Tables 2 and 3). Hannah (1969) used depth of A plus B horizon as an independent variable in his stemwood production regression equation. The B horizon was most commonly a spodic. In these soils the finest texture layer was generally the spodic B horizon when lacustrine or glacial till horizons were lacking. Spodic horizons, formed by illuviation of humus and iron + aluminum sesquioxides (Stobbe and Wright 1959, and Soil Survey Staff 1975), enhance productivity through improved water holding capacity, higher cation exchange capacity, higher base exchange, and better nutrient relations (Soil Survey Staff 1975).

Depth to ground water is also a very important factor for red pine. Earlier discussion demonstrated that good aeration is required for optimal red pine production. A high water table restricts root development and produces a poor site, however, a water table can also provide subirrigation which greatly accelerates tree growth when the roots reach the capillary fringe (Figure 7). A water table 4 to 9 feet below the surface can increase tree growth (Wilde et al.

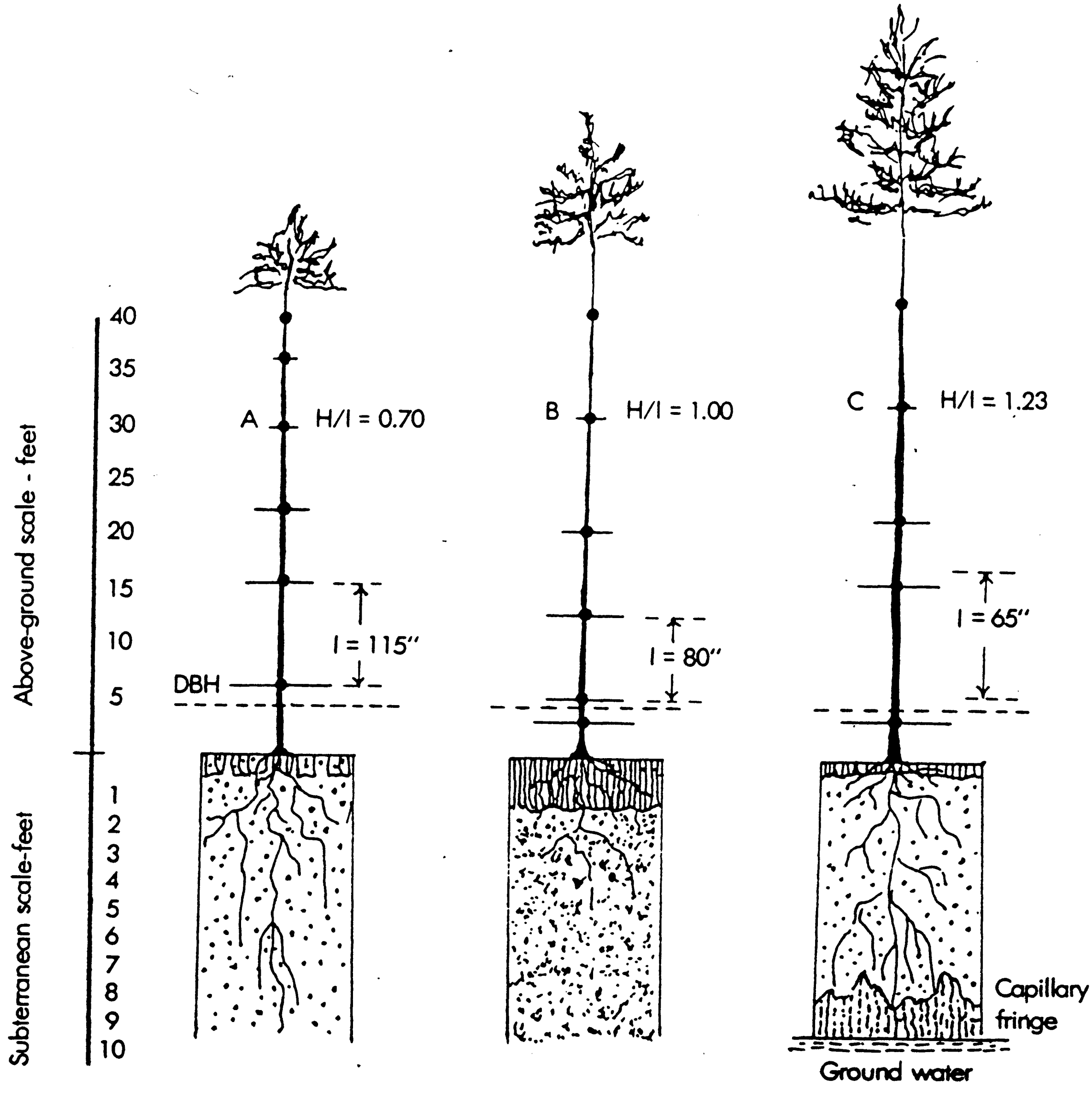


Figure 7. Growth patterns of red pine plantations imparted by environmental conditions. A. Progressively declining height growth retarded by inadequate supply of water and nutrients in a soil with an infertile substratum; B. Progressively accelerated growth on a fertile soil resulting from a suppression of weeds by the closed canopy; C. Explosively increasing growth caused by contact of roots with ground water. Horizontal lines mark 5-year growth periods. All 3 plantations at the age of 30 years exhibit the same site index of 59 (Wilde et al. 1965).

1965), but if the water table is closer to the surface, or fluctuates above 4 feet it may restrict root growth and thus decrease productivity (Stone et al. 1954).

Jurgensen and Leaf (1965) studied how increasing depth to ground water affected growth of a red pine plantation in New York. They found an inverse relationship between depth to ground water and total height, basal area, needle area, needle efficiency, date of leader growth termination, tree nutrient contents, and foliar K concentrations. This study suggests that a stable water table at 3.5 ft. provides optimal moisture and aeration conditions for tree development.

Species Conversion

Wisconsin is the largest paper producing state in the nation, but has not been able to provide softwood fiber to meet the needs of the paper industry. As a result, a major planting effort is underway to restore the softwood component to northern forests. In many cases the planting sites are areas that were previously stocked with low quality northern hardwoods or aspen/birch stands. This conversion from one species group to another is known as site conversion. There has been very little investigation of this management practice in the Lake States, however, the new plantations are expected not only to survive but to produce high yields as well.

Ticknor (1982) provided an economic analysis of hardwood conversion to red pine. In this analysis three areas under the following types of management were compared:

-bare land planted to red pine

-hardwood selection management

-hardwood conversion

The study revealed that there is a considerable economic incentive to convert hardwood stands to red pine plantations. At 6% interest, the present net worth (PNW) was as follows:

scenario	PNW/acre
Bare land pine management	$ 6.72
Hardwood selection management	175.90
Hardwood conversion	384.10

Although there has been much research to identify the soil and topographic features important for tree growth, it is very important to apply this information in species-site selections (Westveld 1951). Soil-site studies have shown that red pine grows best on loamy sand soils with good aeration, and where soils are heavy textured, too wet, or too droughty, conversion attempts can produce disastrous results.

Stoeckeler and Limstrom (1942) provided a site classification summary for reforestation of the major commercial species in northern Wisconsin. They evaluated four major factors that influence reforestation success: soil texture, presence or absence of an overstory, depth to water table, and density of ground cover. Red pine is recommended on sandy to sandy loam soils, with little competition, and with or without a beneficial water table.

Stevens and Wertz (1971) estimated that there is a potential of increasing sawtimber yield 60% by matching species and soils on the Eagle River Ranger District on the Nicolet National Forest. In this analysis the authors recommended increasing both hardwood and red pine acreage, with reductions in spruce-fir, jack pine and aspen-birch forest types. A considerable potential exists for increasing productivity by matching the proper tree species with the proper site.

Jack pine (Pinus banksiana Lamb.) and red pine naturally occur on the same sandy soils. In the study by Stevens and Wertz (1971), the authors recommended that a large portion of the increase in red pine acreage come from existing jack pine stands. Alban (1978) found that red pine mean annual increment averaged 29 cubic feet per acre greater than that of jack pine irrespective of site index. Current annual increment for the last five years showed an even greater difference, with red pine averaging 75 cubic feet per acre more than jack pine. The average stand age was in the mid thirties and the data suggested that the difference between red pine and jack pine may become larger with increasing age. This demonstrates that considerable growth increases can be achieved by converting jack pine to red pine. The ability of red pine to outproduce jack pine was further supported in a study by Alban (1985). This study found that red pine produced significantly higher volumes than jack pine, white spruce (Picea glauca (Moench) Voss), aspen, and black spruce (P. mariana (Mill.) B.S.P.) when growing side by side on five Lake States study sites. In addition Lundgren (1982) suggested that red pine may even outproduce some southern pines because of its ability to produce high volumes per acre in relatively dense stands.

Frederick and Coffman (1978) compared red pine and sugar maple (Acer saccharum Marsh.) growing in adjacent stands on well-drained Kalkaska loamy sand soils in a Tsuga-Maianthemum habitat type in northern Michigan. The red pine basal area and volume was two to three times greater than the sugar maple, and the red pine was almost half the age of the sugar maple. The red pine produced a mean annual volume growth of 1.6 cords/acre while the sugar maple only produced 0.3 cords/acre.

Stone (1976) studied a hardwood conversion site that had been established in 1929. The hardwood stand was cut and then planted with 2-1-2 red pine seedlings. Half of the plantation was hand weeded the 1st, 3rd, 4th and 6th years. The other half was only weeded at the time of planting. A 1974 sampling showed that the cleaned area had a 70% survival and the uncleaned area had a 25% survival. It was determined that a nearby hardwood stand had a mean annual increment of 77 cubic feet per acre which is only about 40% of the mean annual increment of 190 cubic feet per acre on the cleaned area.

Stone (1980) tried to duplicate the study reported earlier by converting a stand of sugar maple that was adjacent to the 1929 study area. In this study 2/3 of the area was hand released one and two years after planting. The other 1/3 of the area was not released from the dense sprouts, suckers and brush that developed. At the end of the third growing season 72% of the released red pine seedlings were alive, although 10% of those were in poor condition and expected to die. The non-released area had a 38% survival rate. The average yearly height growth was 15.0 cm for the released seedlings and 8.0 cm for the non-released seedlings.

These two studies illustrate the tremendous importance of early control of competing vegetation on the survival and growth of red pine seedlings.

GENERAL METHODS

Description of the Study Area

Location

The study area is located on lands of Consolidated Papers, Inc. in Oneida and Forest Counties, Wisconsin (Figure 8).

Climate

Climatic information was collected at the Rhinelander weather station which is located within the study area (USDC 1961). The study area is located in one homogeneous macroclimatic zone which is characterized by long cold winters and warm pleasant summers (Rauscher 1984). The climate is continental, primarily controlled by large air masses. The average annual daily maximum and minimum temperatures are 11.2 ^{o}C and -0.6 ^{o}C respectively. Average frost free season ranges from 87-117 days. The average annual precipitation is 78.2 cm with more than 60% falling between May and September. Average snowfall is 139.7 cm and snow covers the landscape approximately 120 days out of the year.

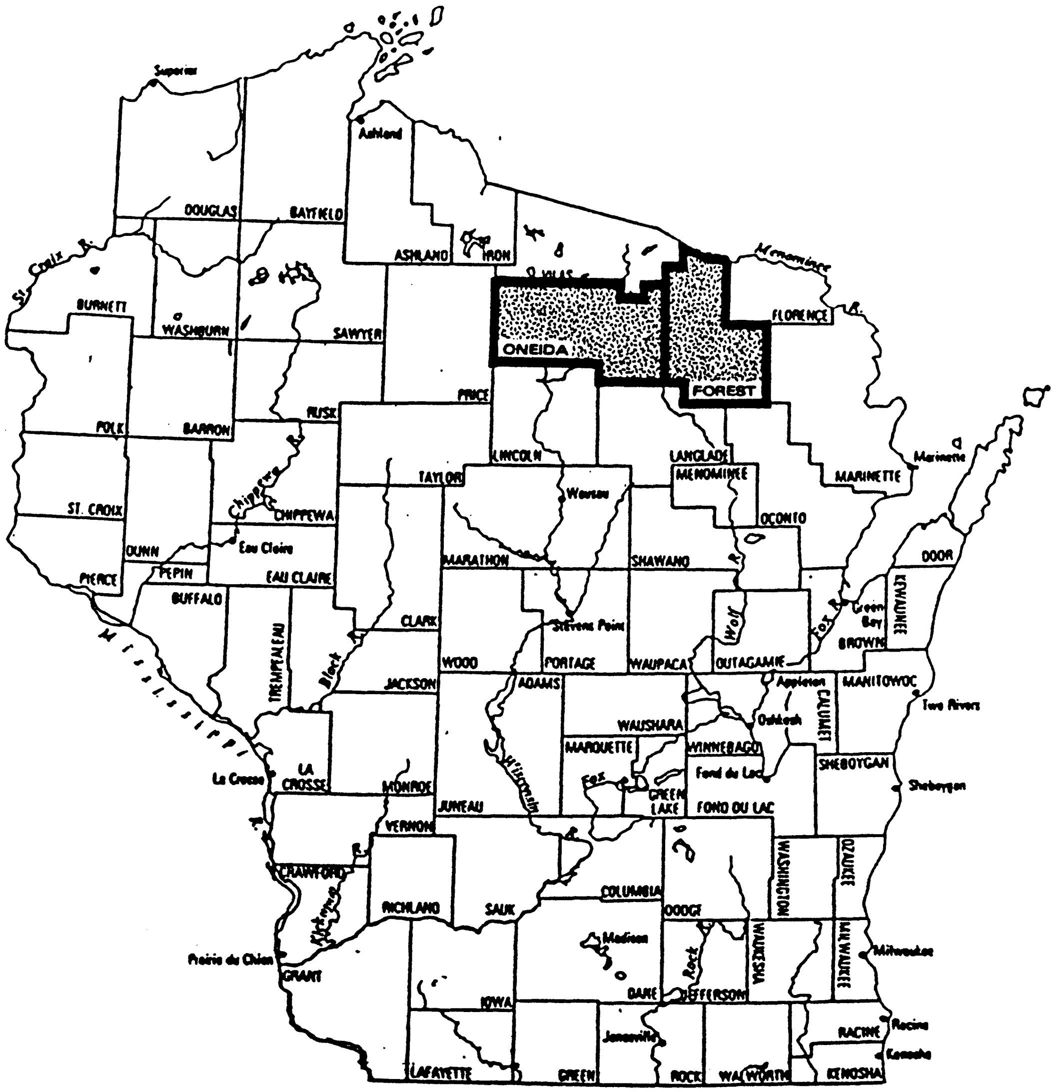


Figure 8. Study area located in Oneida and Forest Counties, Wisconsin.

Geology

The study area is located in the Northern Highlands geologic area. The bedrock is undifferentiated crystalline rock of pre-Cambrian age, and is covered with glacial drift deposited during the Woodfordian substage of the Wisconsin stage of Pleistocene glaciation. Most of the deposits are sorted, stratified, glacio-fluvial sand and gravel. The topography is primarily pitted and unpitted outwash (Hole and Schmude 1959, and Hole 1976).

Ecological Land Types

Ecological Land Types (ELT's) defined by the Nicolet National Forest, were identified within the study area. The three ELT's used in this study were the Stambaugh-Padus, Pence, and Vilas. Figure 9 shows representative soil profiles for the Padus, Pence, and Vilas soil series. The Stambaugh-Padus ELT is composed of the following Soil Resource Inventory (SRI) mapping units:

Stambaugh	20%
Padus	70%
Bohemian	1%
Brimley	.1%
Inclusions	8.9%

The Padus soil is the most common in the ELT and is classified as an Alfic Haplorthod. This soil has

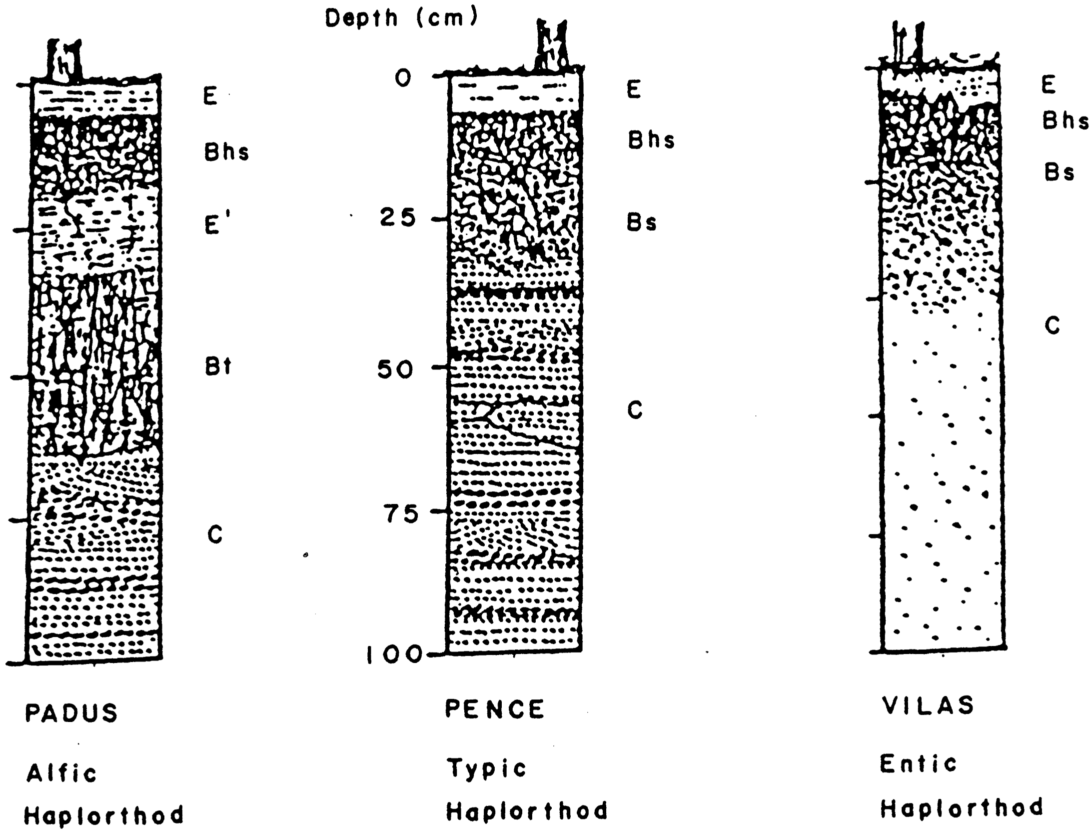


Figure 9. Representative soil profiles for the Padus, Pence, and Vilas soil series (Hole 1976).

developed in a silty or loamy loess cap overlying sand and gravel drift. The solum is 61-127 cm thick, acidic, and is generally well-drained. This ELT has a fairly wide range of productivity for timber. For field identification purposes the Padus ELT was phased using the Tsuga-Maianthemum (TM) habitat type. The TM habitat type is considered to be relatively small in acreage and is central to the Padus soils. By using the TM habitat type and Padus soils together to locate study areas the problem with the wide range of productivity was reduced and the validity of the comparison with the other two ELT's was increased.

The Pence ELT is composed of the following SRI mapping units:

Pence-Crivitz	85%
Worcester-Poskin	5%
Inclusions	10%

The Pence soil is classified as a Typic Haplorthod with a thin loamy loess cap overlying sand and gravel drift. The solum is 25-51 cm thick, acidic, and well-drained. The Tsuga-Maianthemum-Vaccinium (TMV) habitat type was used in conjunction with the Pence soil to locate study areas. The TMV habitat type reflects a soil that is sandier, droughtier and has less spodic development than the TM habitat type (Coffman et al. 1983).

The Vilas ELT is composed of the following SRI mapping units:

Vilas	80.0%
Rousseau	.2%
Croswell	10.2%
Wainola	.1%
Au Gres	1.0%
Inclusions	8.7%

The Vilas soil is classified as a Entic Haplorthod with an acidic, sandy solum having little profile development. The Vilas soil is excessively well-drained and is considered to be the driest of the upland forest types. The Acer-Quercus-Vaccinium (AQV) habitat type was used with the Vilas soil to locate study areas within this ELT. The AQV habitat type reflects the droughty conditions associated with the Vilas soil (Coffman et al. 1983).

Field Methods

Plot Location

In July 1984, 15 study stands were located on Consolidated Papers, Inc. ownership. These stands were scheduled to be clearcut during the fall and/or winter of 1984-85. Five of the stands were typical of the Padus ELT, five were typical of the Pence ELT, and five were typical of the Vilas ELT. Within each stand two plots were located that best represented the modal conditions of the ELT. For each of the three ELT's, ten plots were located in five different stands, for a total of thirty plots. Subjectivity of plot location was reduced by using habitat types as a means of identifying the modal conditions of each ELT. This sampling procedure was described by Mueller-Dombois and Ellenburg (1974) as "subjective without preconceived bias". Slope position, steepness, and aspect were not considered in plot location because of the gentle topography associated with the pitted and unpitted outwash.

Vegetation Measurements

Pre-cut vegetation measurements were made during July and August, 1984. A series of three nested fixed-radius plots and a series of ground vegetation sub-plots (Figure 10) were used. The following measurements by stand strata were made on each of the thirty plots.

a. Overstory stratum (100 sq. m. plot)
   - tally by species, dbh (to the nearest 0.3 cm.), and merchantable height (to a 10 cm. top dia. for 2.4 m. pulp sticks and to a 20 cm. top dia. for 4.8 m. saw-logs) for all trees greater than 12.7 cm. dbh.
   - total age and total height for representative site trees of the dominant species. The number and species of site trees varied from plot to plot.

b. Upper understory stratum (25 sq. m. plot)
   - tally by species and dbh (to the nearest 0.3 cm.) for all woody stems greater than 2.5 cm. dbh but less than 12.7 cm. dbh.

c. Lower understory stratum (4 sq. m. plot)
   - number of stems and percent canopy coverage by species for all woody stems less than 2.5 cm DBH but greater than 1.0 meter in height.

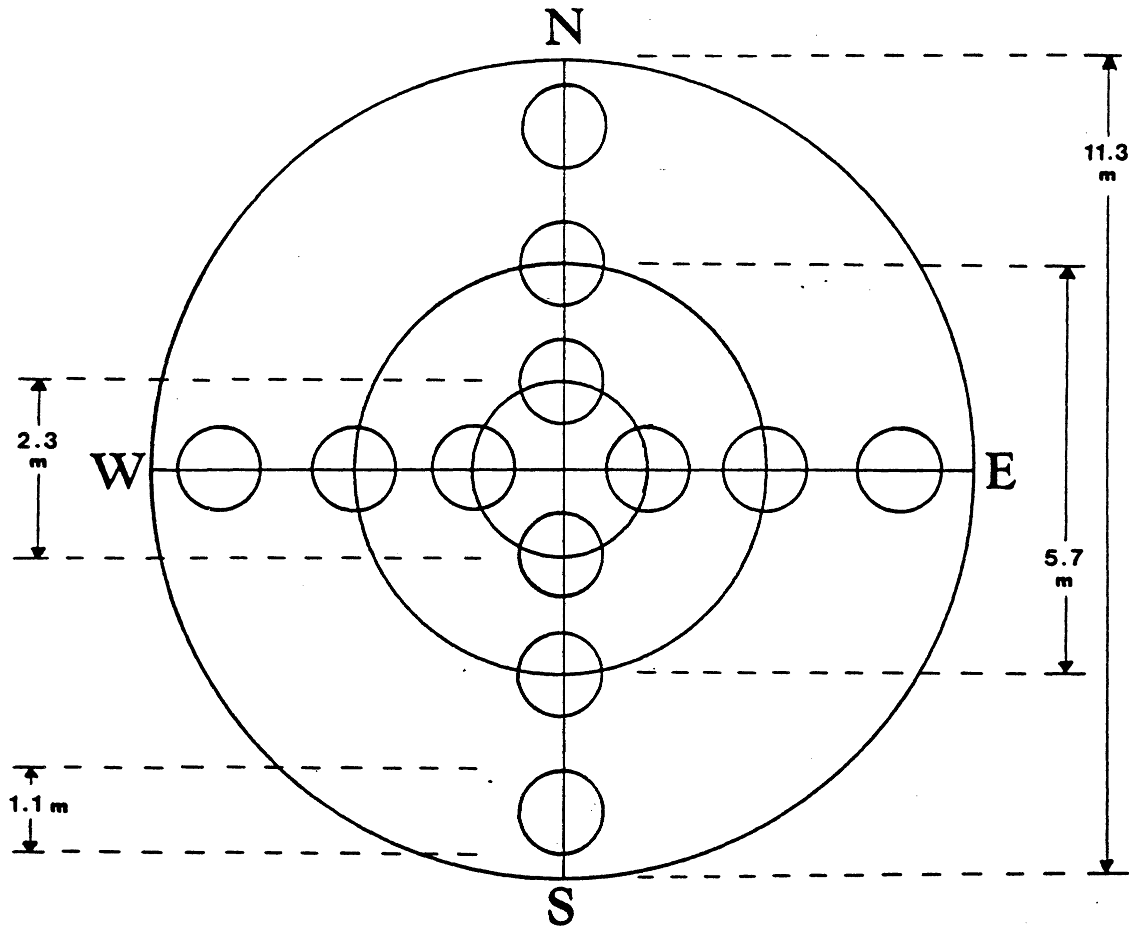


Figure 10. Plot layout, three nested fixed plots and twelve ground vegetation plots.

d. Ground stratum (twelve 1 sq. m. plots)
   -on each of the twelve plots a list of the species present was compiled for all species less than 1.0 meter in height.

Field data was used to determine the following parameters for each strata:

a. Overstory stratum
   -number of stems per ha.
   -basal area, sq. m. per ha.
   -merchantable volume, cu. m. per ha.
   -site index, m
b. Upper understory stratum
   -number of stems per ha.
   -basal area, sq. m. per ha.
c. Lower understory stratum
   -number of stems per ha.
   -percent canopy cover
d. Ground stratum
   -percent frequency by species.

Post-cut vegetation measurements were made during August, 1985. Sample size was reduced to 7 Padus, 4 Pence, and 6 Vilas plots. The other 13 plots were not included because clearcutting had not been completed on 10, 2 were plowed under, and 1 was covered with slash. Percent frequency of occurrence by species was determined for the ground stratum in the same location and manner as the pre-cut vegetation measurements. Visual obstruction was used as a measure of competing vegetation. A one square meter peg board was positioned so that the board center was 2.85 meters from plot center along one of the four cardinal compass directions. The board was aligned parallel to the north/south or east/west compass lines. A picture was taken with the camera positioned 9 meters perpendicular to the alignment of the board and 0.5 meters off the ground (Figures 11 and 12). This process was repeated on each of the four cardinal compass lines for the 17 plots remaining in the post-cut vegetation analysis. The number of dots visually obstructed was determined for each of the 68 photographs.

Seedling Measurements

In May, 1985 twenty 2-0 bare root red pine seedlings were planted on each study plot. Johnson and Haag (1984) demonstrated that twenty seedlings were sufficient to evaluate treatment effects on diameter and height with a 95% probability and 10% allowable error. Of the original 30 plots, 10 were not clearcut and alternate planting areas had to be selected. The new sites were adjacent to the original plots, cut within the past year, and had the correct soil/habitat type relationship. This provided a sample size of twenty seedlings on 8 Padus, 8 Pence, and 8 Vilas ELT's, and on a six plot subsample (2 Padus, 2 Pence, and 2 Vilas) an extra 10 seedlings were planted for a total of 30 on these six plots. Diameter (to the nearest 0.01 mm) and height (to the nearest 0.1 cm) were measured at the time of planting and in August 1985. A tally of dead or dying seedlings was recorded in August 1985.

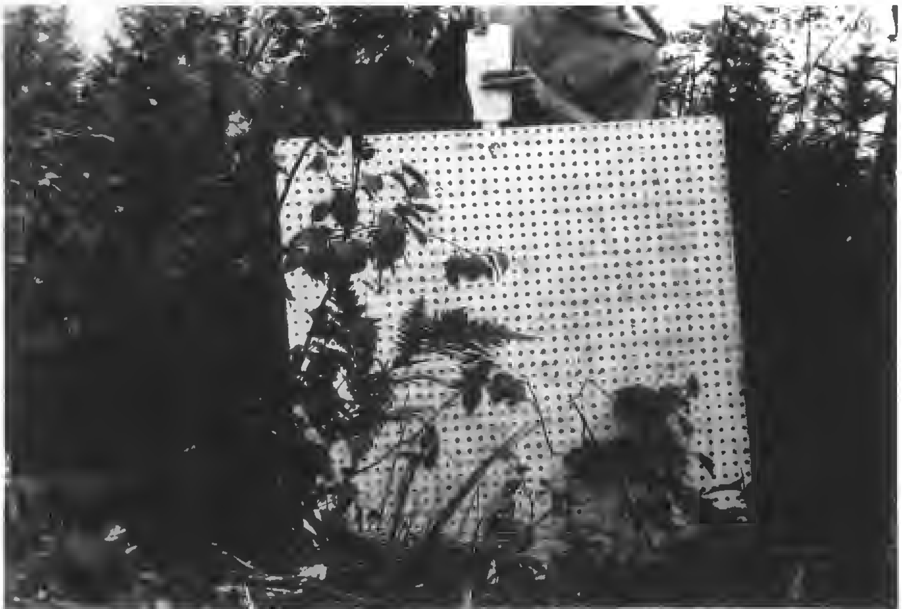


Figure 11. Example of ocular obstruction dot count photograph taken on plot 3 south compass line.

Figure 12. Example of ocular obstruction dot count photograph taken on plot 24 east compass line.

Factors Influencing Seedling Survival and Growth

On July 3, 17, 30, and August 13, 1985 two Padus, Pence, and Vilas plots were sampled in the following manner:

- red pine seedling diameter (to the nearest 0.01 mm) and height (to the nearest 0.1 cm) were measured on all thirty seedlings planted on the 6 plot subsample.
- pre-dawn seedling moisture status was measured on five seedlings on each of the 6 plots with a Soil Moisture model 3000 series plant water status console (pressure bomb). Individual pine fascicles were used in this study and have been shown to have a linear function with slope of 1 when compared with stem pressure readings (Johnson and Nielsen 1969).
- soil water tension was measured at two locations at a depth of 15.5 cm on each of the 6 plots with a 2900F soilmoisture probe.
- two mineral soil composite samples, consisting of three 15.5 cm deep probe samples, were collected on each of the 6 plots. Soil samples were bagged in the field and returned to the lab for gravimetric soil moisture determination and nitrogen analysis.
- air temperature, relative humidity, and two soil temperature measurements (at a depth of 4.5 cm) were recorded when pre-dawn seedling moisture status was measured.

Soil Descriptions and Sampling

On each of the thirty plots soils were sampled in the following manner.

- a soil pit to the C horizon was used to provide a complete soil profile description. This included soil horizon depth, color, mottling, texture, structure, consistence, reaction, and special features.
- bulk density samples were collected from each master horizon using an impact sampler.
- composite samples for nutrient analysis were collected from the pit and four auger samples (one from each of the four plot quadrants) for each horizon.

-0.01 sq. m. samples of the forest floor (Oi+Oe and Oa horizons) were collected from each quadrant and then composited.
-all samples were bagged in the field and allowed to air dry prior to analysis.

Laboratory Methods

Composite soil samples were dried at room temperature, gently ground, and passed through a 2 mm sieve. Each sample was subjected to the following physical and chemical analysis:

-particle size analysis using the hydrometer method (Day 1965).
-total nitrogen by the micro-Kjeldahl method.
-available phosphorus extracted by a 0.025 N HCL + 0.03 N NH_4 F solution with an ammonium molybdate color developer (read with a photo-electric colorimeter).
-the same extract was used to determine available potassium using a flame photometer.
-exchangeable calcium and magnesium was determined by using a 1 N NH_4 OAc extracting solution at pH 7.0 and read with a flame photometer.
-pH was measured with a glass electrode in 10 ml of distilled water to 7.5 grams of soil mix.
-lime requirement was determined using the SMP procedure (Shoemaker et al. 1961).
-organic matter content was determined by the Walkley-Black method (Walkley and Black 1934).

Soil nutrient analysis (except total N) was conducted at the UWEX Soil and Forage Testing Lab. in Marshfield, Wisconsin.

Forest floor samples were dried at 65 ^{o}C until a constant weight was obtained. The samples were then weighed and ground using a Wiley Mill equipped with a 1 mm. sieve. The Oa samples were first passed through a 2mm sieve to separate mineral from organic matter.

Following Wiley Mill grinding the mineral and organic portions were remixed. Total nitrogen was determined by the micro-Kjeldahl method. Total phosphorus, potassium, calcium and magnesium were analyzed by digesting in concentrated nitric and perchloric acid followed by analysis with a plasma emission spectrophotometer. Forest floor nutrient analysis (except total N) was conducted at the UWEX Soil and Plant Analysis Lab., Madison, Wisconsin.

The twelve mineral soil composite samples collected on July 3, 17, 30, and August 13, 1985 were subjected to the following chemical analyses:

-total nitrogen by the micro-Kjeldahl method.
-ammonium and nitrate concentrations using the steam distillation procedure of Bremmer (1965). Nitrate concentrations may include minute quantities of nitrite, which seldom occurs in high concentrations in forest soils.

OBJECTIVE 1

The first objective was to determine if there was a significant difference in soil-site characteristics between the three ELT's.

Statistical Methods

Discriminant analysis is a statistical technique that uses a linear combination of discriminator variables to discriminate between two or more qualitative groups (Klecka 1980). Soil-site and understory vegetation parameters were the quantitative discriminator variables and the three ELT's were the qualitative groups. Analysis of variance (ANOVA) followed by Scheffe tests were conducted to evaluate the significance of the differences for individual discriminator variables (Scheffe 1959).

Minimum Wilks's lambda was the stepwise procedure used to select discriminator variables. This procedure takes into consideration both the distinctness between groups and the cohesiveness within groups. A variable that increases group cohesiveness without affecting group separation could be selected rather than a variable that only increases group separation (Klecka 1980). This stepwise procedure was performed on four data sets:

1. Soil variables
2. Vegetation variables
3. Soil and vegetation variables
4. Post-cut vegetation variables

Discriminator soil variables were selected from the complete set of physical and chemical parameters (Appendix 1). In addition, red pine site index was included in the discriminant analysis to provide a comparison of productivity. Site index was estimated using the following soil property regression equation (Alban 1976):

$$\text{Site index (ft)} = 49.03 - 0.317(X_1) + 0.313(X_2) + 4.98(X_3) \quad (2)$$

where X_1 = percent of coarse material (>2mm) by weight in 0 to 10 inch layer, X_2 = thickness of A and B horizons (inches), and X_3 = 1 for soils with textural bands totaling more than 6 inches in thickness and 0 for soils lacking fine textured bands. The Padus soil is a bisequum and is commonly the only one of the three ELT's that has fine textured bands. The importance of textural bands to red pine productivity has been established by White and Wood (1958), Hannah (1969), Hannah and Zahner (1970), and Alban (1974 and 1976).

Vegetation variables available in the stepwise selection included percent frequency of occurrence for ground flora (Appendix 2). Overstory, upper understory, lower understory, frequency of occurrence for tree seedlings, and site index determined from total age and total height for a representative site tree were excluded because these parameters are closely related to past management activities and not dependent on the ELT (Appendix 3).

The third data set was a combination of soil variables (Appendix 1) and vegetation variables (Appendix 2).

Post-cut vegetation variables consisted of the percent frequency of occurrence for ground vegetation measured in August 1985. Data for tree seedlings was excluded to remain consistent with the previous vegetation variable data set and because of the influence of past management. Measurements were taken in the same way and in the same location as pre cut, August 1984 measurements. Sample size was reduced to 7 Padus, 4 Pence, and 6 Vilas because the other 13 plots were not cut.

The "U" or "Jackknife" method for estimation of error rates was used on all four data sets to test the discriminant analysis classification results. This procedure is recommended when sample size is small relative to the number of variables (Lachenbruch and Mickey 1968). The "U" technique holds one plot out when deriving the discriminant and classification functions. A classification function is derived for all three ELT's, then discriminator variable raw data values are used in each function to calculate classification scores for the withheld plot. The plot is classified into the ELT that produces the highest classification score (Klecka 1980). This process was repeated for all thirty plots and a percent correct classification calculated for all four data sets.

Results and Discussion

Soil Variables

The discriminant analysis produced two canonical discriminant functions (Table 9). Table 10 shows the relative importance of each function. Function 1 had a very large eigenvalue compared to function 2, accounting for 96.27% of the variance. Both functions were highly correlated with the ELT's (0.9996 and 0.9896 respectively), and the chi-squared statistics were significant. This tests the significance of residual discriminating power.

Table 9. Unstandardized and standardized canonical discriminant function coefficients for soil variables used to discriminate the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

	Coefficients for Function 1		Coefficients for Function 2	
Variable	Unstandardized	Standardized	Unstandardized	Standardized
P, E Horizon (kg/ha)	0.147869	3.20839	0.003615	0.07846
% Clay, E Horizon	-5.974059	-10.81466	-0.507659	-0.91900
OM, E Horizon (kg/ha)	0.000207	2.49918	0.000119	1.44154
SMP, E Horizon	5.542859	7.78781	2.520198	3.54092
Ph, Bhs Horizon	-1.394049	-2.11588	-0.358106	-0.54353
Depth, Bhs Horizon (cm)	3.324186	18.82293	0.609376	3.45055
P, Bhs Horizon (kg/ha)	-0.028513	-4.56705	-0.008176	-1.30963
SMP, Bhs Horizon	-3.747315	-6.57018	-2.689284	-4.71513
Depth, Bs Horizon (cm)	1.685676	16.43603	0.361969	3.52935
% Silt, Bs Horizon	0.998938	8.78595	0.410154	3.60742
SMP, Bs Horizon	2.908600	3.75499	0.960347	1.23980
Ph, C Horizon	-2.026627	-3.17097	-0.658081	-1.02967
P, C Horizon (ppm)	0.090332	2.15199	0.038638	0.92048
% Clay, C Horizon	-2.864494	-5.99210	-0.199393	-0.41710
P, Oi Layer (kg/ha)	0.072520	0.23428	1.183325	3.82277
K, Oi Layer (kg/ha)	1.308609	4.66166	-1.368644	-4.87552
Mg, Oi Layer (kg/ha)	-0.225424	-5.74745	-0.010790	-0.27511
K, Oa Layer (kg/ha)	0.161655	2.24903	-0.055623	-0.77386
Ca, Oa Layer (kg/ha)	0.010973	1.22559	0.017090	1.90874
Mg, Oa Layer (kg/ha)	0.157975	4.73496	0.109274	3.27526
Site Index (ft)	-15.44131	-30.67217	-1.755424	-3.48692
(Constant)	618.7264		59.64185	

Table 10. Statistics for evaluating the degree of association between Ecological Land Types and canonical discriminant functions, and the significance of residual discrimination for soil variables on the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

Function	Eigenvalue	Percent of Variance	Cumulative Percent	Canonical Correlation	:	After Function	Wilks' Lambda	Chi-squared	D.F.	Significance
					:	0	0.0000168	186.85	42	0.0000
1	1223.81895	96.27	96.27	0.9995917	:	1	0.0206341	65.97	20	0.0000
2	47.46349	3.73	100.00	0.9896292	:					

Before any functions were derived the discriminator variables had a highly significant (F Prob.=0.0000) amount of discriminating power, so function 1 was derived. After the derivation of function 1 the discriminator variables still had a highly significant (F Prob.=0.0000) amount of discriminating power, so function 2 was derived. Table 10 shows that both functions were important in discriminating between the three ELT's, but function 1 accounted for a very large percent of the variance (96.27%).

Relative importance of function 1 is apparent in the territorial map (Figure 13). The horizontal axis (function 1) produces a very clear separation of the three ELT's. Greatest separation is between Padus on the far left and Vilas/Pence on the right. The vertical axis (function 2) did not produce much separation.

A matrix of pairwise F ratios and their significances (Table 11) tests the hypothesis that ELT centroids are equal. The pairwise comparison showed that the soil discriminator variables were effective in discriminating between ELT's.

Percent correct classification is another measure of the discrimination success. The idea is to compare an individual plot to the ELT centroids and classify that

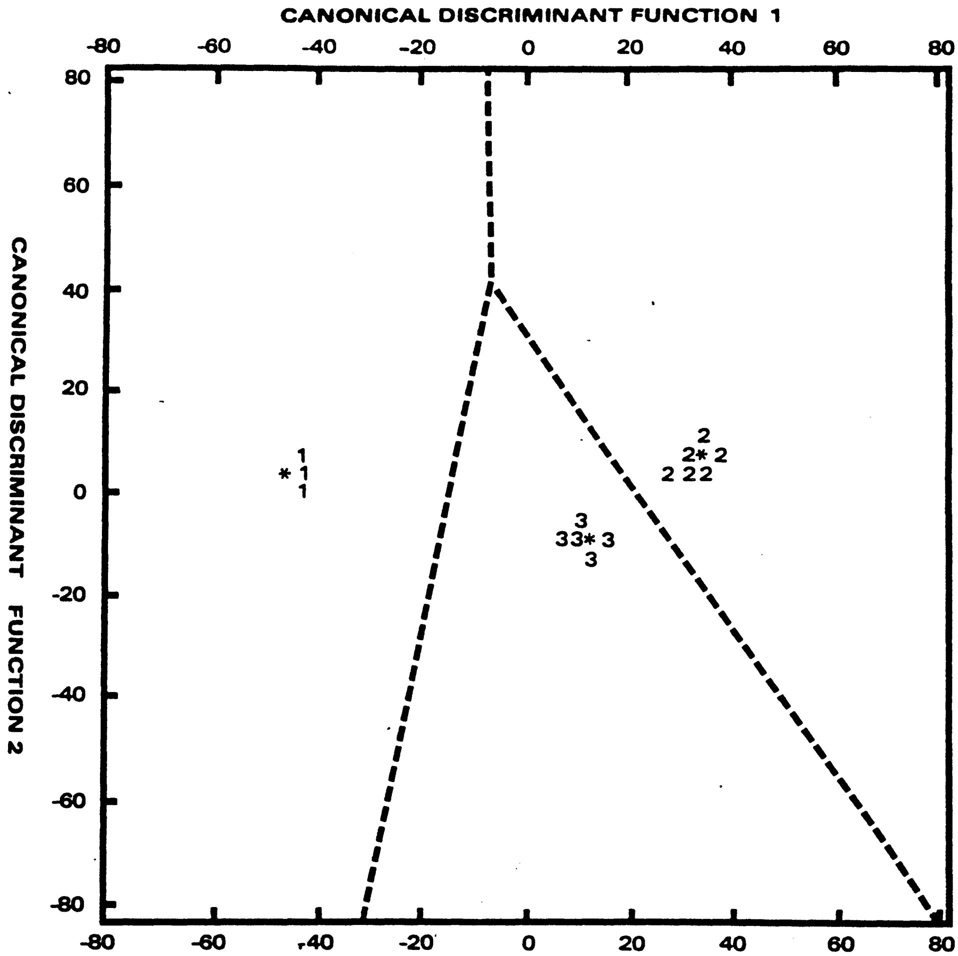


Figure 13. Territorial map showing Ecological Land Type centroids (*) and plot clusters using soil variables for the Padus (1), Pence (2), and Vilas (3) ELT's in northeastern Wisconsin.

Table 11. F statistics and significances between pairs of Ecological Land Types in northeastern Wisconsin using soil variables. Each F statistic has 21 and 7 degrees of freedom.

	Padus	Pence
Pence	383.66 0.0000	
Vilas	207.83 0.0000	44.149 0.0000

plot into the ELT it is closest to. This is accomplished by using raw data scores with the three classification functions (Table 12). The plot is classified into the ELT with the highest classification score. The SPSS program discriminant (Nie et al. 1975) classification results are shown in table 13. This 100.0% correct classification has a built in bias. All thirty plots are used to derive the functions and then the functions are used to classify the same thirty plots. Results of the "U" method of error estimation are also presented in table 13. Soil discriminator variables produced a 66.7% correct classification. Eighty percent of the Padus plots and 70.0% of the Vilas plots were correctly classified, while only 50.0% of the Pence plots were correctly classified.

The ANOVA and Scheffe tests (Table 14) help explain the reason for the low percent correct classification in the Pence ELT. Five soil discriminator variables had significant differences between the Padus and Vilas, but the Pence was intermediate and non significant when compared to the Padus or Vilas. For these five soil variables there is a clear distinction between the Padus and Vilas, which help produce better classification results. The Pence is not significantly different, which produced the poorer classification results.

Table 12. Classification function coefficents for soil variables used to classify the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

Variable	Padus	Pence	Vilas
P, E Horizon (kg/ha)	-101.1259	-89.46885	-92.75558
% Clay, E Horizon	3977.319	3504.920	3643.283
OM, E Horizon (kg/ha)	-0.142731	-0.125931	-0.132305
SMP, E Horizon	-3685.203	-3238.737	-3398.712
pH, Bhs Horizon	964.8463	853.6571	889.6395
Depth, Bhs horizon (cm)	-2235.215	-1971.053	-2053.084
P, Bhs Horizon (kg/ha)	19.52061	17.24301	17.99211
SMP, Bhs Horizon	2620.960	2315.197	2438.546
Depth, Bs Horizon (cm)	-1156.971	-1022.804	-1065.218
% Silt, Bs Horizon	-688.4833	-608.1965	-636.3482
SMP, Bs Horizon	-1886.344	-1653.505	-1731.868
pH, C Horizon	1381.445	1219.254	1273.684
P, C Horizon (ppm)	-58.35021	-51.08383	-53.65342
% Clay, C Horizon	1947.670	1721.335	1787.000
P, Oi Layer (kg/ha)	-192.1423	-181.7183	-201.5502
K, Oi Layer (kg/ha)	-726.4910	-628.9078	-636.3962
Mg, Oi Layer (kg/ha)	151.8665	134.0744	139.1663
K, Oa Layer (kg/ha)	-112.2899	-99.78327	-102.4578
Ca, Oa Layer (kg/ha)	-8.632711	-7.700598	-8.203916
Mg, Oa Layer (kg/ha)	-106.3995	-93.52576	-98.66262
Site Index (ft)	10377.56	9154.768	9519.234
(Constant)	-230121.1	-180725.2	-194689.5

Table 13. Classification results from SPSS program Discriminant and validation results using the "U" method of error estimation for soil variables on the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

Classification results using SPSS program Discriminant

Actual ELT	No. of cases	Predicted ELT Membership Padus	Pence	Vilas
Padus	10	10 (100.0%)	0 (0.0%)	0 (0.0%)
Pence	10	0 (0.0%)	10 (100.0%)	0 (0.0%)
Vilas	10	0 (0.0%)	0 (0.0%)	10 (100.0%)

Percent of ELT's correctly classified = 100.0%

Validation results using the "U" method of error estimation

Actual ELT	No. of cases	Predicted ELT Membership Padus	Pence	Vilas
Padus	10	8 (80.0%)	1 (10.0%)	1 (10.0%)
Pence	10	1 (10.0%)	5 (50.0%)	4 (40.0%)
Vilas	10	0 (0.0%)	3 (30.0%)	7 (70.0%)

Percent of ELT's correctly classified = 66.7%

Table 14. Means, standard deviations (in parentheses), and F statistics for soil discriminator variables presented in order of stepwise inclusion for the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

Variable	F Prob	Padus	Pence	Vilas
Site Index (m)	0.0000[1]	18.4 (0.9) a[2]	16.7 (0.4) b	16.5 (0.4) b
% Clay, E Horizon	0.0043	8.2 (2.8) a	6.3 (1.1) ab	5.2 (1.0) b
Mg, Oa Layer (kg/ha)	0.0062	85.4 (25.7) ab	105.1 (42.3) a	58.2 (15.6) b
pH, Bhs Horizon	0.0016	5.1 (0.1) a	4.8 (0.2) b	4.9 (0.1) b
K, Oi Layer (kg/ha)	0.3422	14.0 (4.3) a	11.7 (3.3) a	12.9 (3.0) a
Depth, Bs Horizon (cm)	0.0063	35.8 (12.0) a	25.4 (9.2) ab	20.9 (7.5) b
Depth, Bhs Horizon (cm)	0.7660	15.3 (5.5) a	15.8 (6.7) a	14.0 (4.5) a
% Clay, C Horizon	0.0041	7.4 (3.2) a	5.5 (1.3) ab	4.0 (0.9) b
SMP, Bhs Horizon	0.4634	62.4 (2.2) a	61.5 (1.6) a	62.3 (1.3) a
SMP, E Horizon	0.0093	66.5 (1.3) a	65.4 (1.5) ab	64.4 (1.4) b
P, Bhs Horizon (kg/ha)	0.9556	173.9 (133.5) a	153.2 (170.7) a	158.4 (173.3) a
% Silt, Bs Horizon	0.0000	29.8 (13.3) a	17.3 (7.0) b	8.1 (2.4) b
P, Oi Layer (kg/ha)	0.1391	12.2 (4.1) a	9.2 (2.9) a	10.5 (2.4) a
Ca, Oa Layer (kg/ha)	0.0088	360.9 (160.4) a	339.0 (93.1) a	205.7 (55.0) b
P, E Horizon (kg/ha)	0.0571	35.4 (29.0) a	19.3 (23.0) a	11.3 (6.1) a
Mg, Oi Layer (kg/ha)	0.2921	27.9 (43.8) a	11.3 (5.3) a	12.9 (2.9) a
SMP, Bs Horizon (kg/ha)	0.2998	64.5 (1.4) a	64.2 (0.9) a	65.1 (1.5) a
pH, C Horizon	0.0375	5.1 (1.2) a	5.1 (1.9) a	5.2 (1.4) a
P, C Horizon (ppm)	0.0268	34.3 (13.3) a	55.8 (28.3) ab	64.0 (27.0) b
OM, E Horizon (kg/ha)	0.1546	24900 (18400) a	14200 (7300) a	18200 (6500) a
K, Oa Layer (kg/ha)	0.0188	65.2 (15.1) ab	72.8 (14.5) a	53.9 (11.8) b

1 Underlined values represent $P \leq 0.05$.

2 Means within a row followed by the same letter are not significantly different at the 0.05 level using the Scheffe test.

Analysis of the soil discriminator variables infers that a productivity gradient exists from Padus (high) to Vilas (low). Site index is the most powerful indicator of this trend. The stepwise procedure selected site index first, indicating that it accounted for the most discriminating power. Site index had the largest standardized coefficient for canonical discriminant function 1, which accounted for the greatest percent of variance and clearly separated Padus from Pence and Vilas. The Scheffe test showed that Padus had a significantly higher site index then Pence and Vilas. There should not be much auto correlation of site index with soil features because the regression equation (Alban 1976) depends largely on fine textured bands. This productivity gradient was also indicated with % clay in the E horizon, pH of the Bhs horizon, depth of the Bs horizon, % clay in the C horizon, % silt in the Bs horizon, and Ca in the Oa layer. These variables are important in site productivity because the higher % silt and clay will increase water holding capacity and cation exchange capacity, pH can influence nutrient availability, and depth of the Bs horizon is important in nutrient content and depth of rooting zone. This analysis has shown that the Padus ELT is potentially the most productive ELT.

Vegetation Variables

The discriminant analysis produced two canonical discriminant functions (Table 15). Table 16 shows the relative importance of each function. Function 1 had a large eigenvalue compared to function 2, accounting for 81.85% of the variance, both functions were highly correlated with the ELT's (0.9996 and 0.9983 respectively), and the chi-squared statistics were significant. Both functions were important in discriminating between the ELT's and were retained for further analysis.

The territorial map (Figure 14) shows that function 1 clearly separates Pence from Padus and Vilas, and function 2 separates Padus from Vilas. A matrix of pairwise F ratios and their significances (Table 17) showed that the vegetation discriminator variables were able to statistically separate the ELT centroids.

Percent correct classification (Table 18) was determined using the derived classification functions (Table 19). The SPSS program discriminant and "U" technique produced 100.0% and 56.7% correct classification respectively. Compared with the soil discriminator variables there was a 10.0% decrease in correct classification. The Padus classification dropped from 80.0% to 60.0%, Pence dropped from 50.0% to 10.0%, and Vilas increased from 70.0% to 100.0%.

Table 15. Unstandardized and standardized canonical discriminant function coefficients for vegetation variables used to discriminate the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

	Coefficients for Function 1		Coefficients for Function 2	
Variable	Unstandardized	Standardized	Unstandardized	Standardized
Ground pine	-10.80544	-4.00152	23.45349	8.68539
Beaked hazel	107.4935	29.90406	8.364161	2.32686
Large leaf aster	-5.599166	-1.59677	14.87986	4.24343
Woodland grass	33.90345	7.23177	16.25782	3.46787
Low sweet blueberry	30.13787	6.97078	-31.67718	-7.32681
Common strawberry	-158.0742	30.25191	-26.00633	-4.97704
Rosey twisted stalk	43.58687	1.62439	-88.56460	-3.30061
Rubus Spp.	-22.60352	-6.70878	-7.036282	-2.08838
Greenish flowered pyrola	-111.1773	-2.39216	87.73419	1.88774
Shining clubmoss	99.39246	4.53662	51.26194	2.33978
Wintergreen	-39.49987	-10.03420	-18.69517	-4.74916
Solomon's seal	59.38573	6.86785	24.65976	2.85186
Twinflower	1.161106	0.20107	20.99408	3.63566
Sweetfern	-4.667435	-0.42344	-20.59580	-1.86849
Barren strawberry	-21.70054	-7.59375	1.890233	0.66146
Spinulose shield fern	837.0234	30.01646	-8.008361	-0.28719
Goldtread	-494.6754	-28.04866	-47.88416	-2.71509
White baneberry	514.8046	7.83250	51.90985	0.78978
Field pussytoes	1218.426	18.53776	116.2738	1.76905
Virgins bower	-616.7477	-9.38352	12.61917	0.19199
White lettuce	-555.8236	-11.27545	-56.01900	-1.13640
(Constant)	-36.91586		-17.56030	

Table 16. Statistics for evaluating the degree of association between Ecological Land Types and canonical discriminant functions, and the significance of residual discrimination for vegetation variables on the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

Function	Eigenvalue	Percent of Variance	Cumulative Percent	Canonical Correlation	:	After Function	Wilks' Lambda	Chi-squared	D.F.	Significance
					:	0	0.0000025	219.21	42	0.0000
1	1337.17613	81.85	81.85	0.9996263	:	1	0.0033609	96.82	20	0.0000
2	296.54262	18.15	100.00	0.9983182	:					

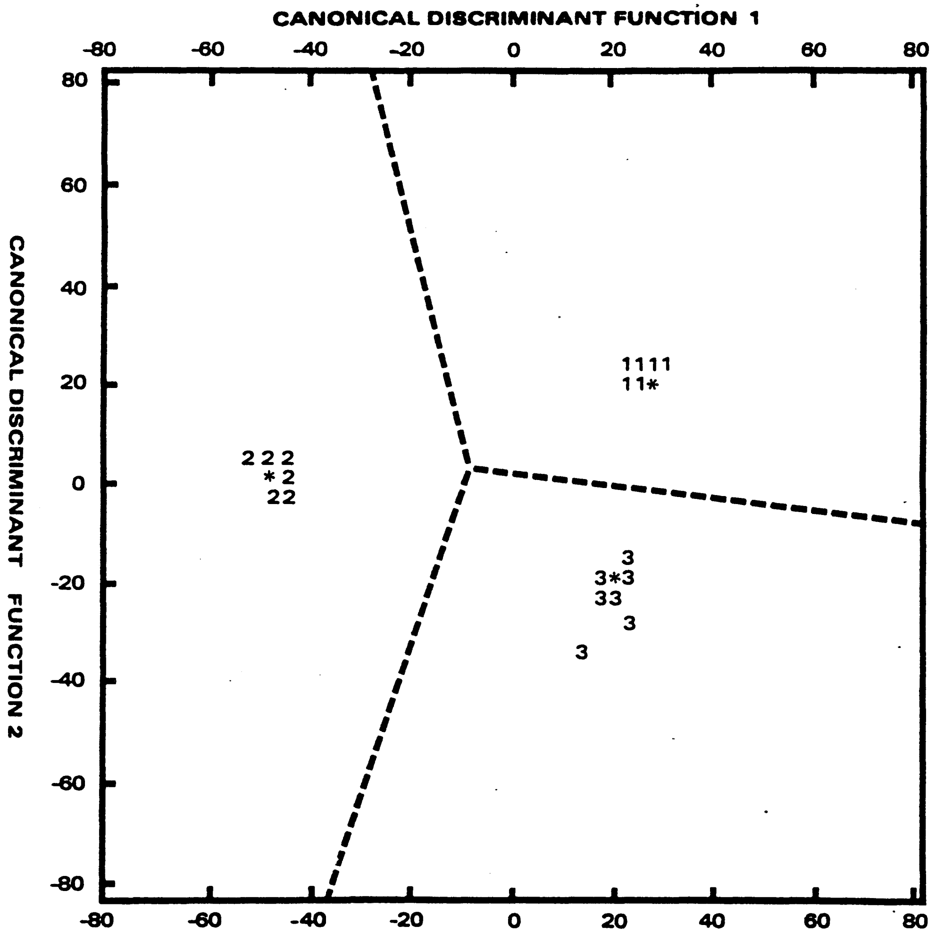


Figure 14. Territorial map showing Ecological Land Type centroids (*) and plot clusters using vegetation variables for the Padus (1), Pence (2), and Vilas (3) ELT's in northeastern Wisconsin.

Table 17. F statistics and significances between pairs of Ecological Land Types in northeastern Wisconsin using vegetation variables. Each F statistic has 21 and 7 degrees of freedom.

	Padus	Pence
Pence	375.23 0.0000	
Vilas	99.932 0.0000	341.69 0.0000

Table 18. Classification results from SPSS program Discriminant and validation results using the "U" method of error estimation for vegetation variables on the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

Classification results using the SPSS program Discriminant

Actual ELT	No. of cases	Predicted ELT Membership Padus	Pence	Vilas
Padus	10	10 (100.0%)	0 (0.0%)	0 (0.0%)
Pence	10	0 (0.0%)	10 (100.0%)	0 (0.0%)
Vilas	10	0 (0.0%)	0 (0.0%)	10 (100.0%)

Percent of ELT's correctly classified = 100.0%

Validation results using the "U" method of error estimation

Actual ELT	No. of cases	Predicted ELT Membership Padus	Pence	Vilas
Padus	10	6 (60.0%)	2 (20.0%)	2 (20.0%)
Pence	10	3 (30.0%)	1 (10.0%)	6 (60.0%)
Vilas	10	0 (0.0%)	0 (0.0%)	10 (100.0%)

Percent of ELT's correctly classified = 56.7%

Table 19. Classification function coefficients for vegetation variables used to classify the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

Variable	Padus	Pence	Vilas
Ground pine	176.3590	572.8774	-709.3636
Beaked hazel	7164.042	-1140.329	6319.138
Large leaf aster	216.8144	373.0941	-351.0931
Woodland grass	2820.810	-44.07980	2010.163
Low sweet blueberry	810.4564	-904.0959	1932.896
Common strawberry	-10993.40	1465.823	-9203.298
Rosey twisted stalk	-222.0714	-1930.533	3109.351
Rubus spp.	-1758.727	82.70274	-1370.205
Greenish flowered pyrola	-4065.789	2784.465	-7042.898
Shining clubmoss	8323.009	-140.7382	5802.655
Wintergreen	-3230.487	102.8649	-2295.869
Solomon's seal	4704.109	-245.2026	3436.699
Twinflower	844.1608	377.3706	-0.153894
Sweetfern	-1145.538	-419.9739	-300.4769
Barren strawberry	-1273.454	338.4556	-1245.872
Spinulose shield fern	55301.71	-10042.87	49644.82
Goldthread	-33430.73	4954.680	-29167.27
White baneberry	34832.28	-5152.571	30312.34
Field pussytoes	81653.02	-12863.28	71218.43
Virgins bower	-38802.47	7750.814	-36376.37
White lettuce	-37731.77	5438.540	-32852.76
(Constant)	-2755.344	-291.2195	-1787.786

ANOVA and Scheffe tests (Table 20) showed that the decline in Padus and Pence was because only one variable (Solomon's seal) had a significant difference between these two ELT's, compared with 3 vegetative discriminator variables having significant differences between Padus/Pence and Vilas. Because of high standard deviations, the majority of variables did not have significant differences. The result was a reduction in correct classification for Padus, Pence, and the overall percentage. Vilas had a 30.0% increase in correct classification because three of the four variables that had significant differences focused on the Vilas ELT. Wintergreen and low sweet blueberry were the first variables selected in the stepwise procedure, indicating that they accounted for the most discriminating power. The F probabilities were highly significant ($P \leq 0.0000$) and the Scheffe tests showed that both wintergreen and low sweet blueberry had a significantly higher occurrence on the Vilas. Barren strawberry had a significantly higher occurrence on the Vilas when compared with Padus, but Pence was intermediate and non significant. Wintergreen, low sweet blueberry, and barren strawberry are considered modal for the xeric forests of northern Wisconsin (Curtis 1959).

Table 20. Means, standard deviations (in parentheses), and F statistics for vegetation discriminator variables presented in order of stepwise inclusion for the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

Variable	F Prob.	Padus	Pence	Vilas
Wintergreen	0.0000[1]	0.8 (2.6) a[2]	18.3 (24.2) a	70.0 (9.2) b
Low sweet blueberry	0.0000	5.0 (10.5) a	25.0 (25.5) a	65.0 (29.1) b
Ground pine	0.3742	45.0 (42.7) a	36.7 (40.3) a	21.7 (25.8) a
Solomon's seal	0.0137	16.7 (18.0) a	1.7 (3.5) b	3.3 (8.1) ab
Large leaf aster	0.2424	80.0 (15.3) a	75.8 (22.4) a	59.2 (41.3) a
White lettuce	0.1248	0.0 (0.0) a	1.7 (3.5) a	0.0 (0.0) a
Beaked hazel	0.0976	40.8 (25.3) a	35.0 (29.1) a	61.7 (28.9) a
Spinulose shield fern	0.2998	2.4 (5.6) a	0.8 (2.6) a	0.0 (0.0) a
Goldthread	0.4046	2.5 (7.9) a	3.3 (5.8) a	0.0 (0.0) a
Common strawberry	0.1553	13.3 (15.3) a	25.0 (25.1) a	8.3 (15.2) a
Rosey twisted stalk	0.8473	1.7 (5.3) a	0.8 (2.6) a	0.8 (2.6) a
Barren strawberry	0.0103	0.8 (2.6) a	18.3 (38.7) ab	51.7 (46.6) b
Field pussytoes	0.3811	0.0 (0.0) a	0.0 (0.0) a	0.8 (2.6) a
Virgins bower	0.3811	0.0 (0.0) a	0.8 (2.6) a	0.0 (0.0) a
White baneberry	0.3811	0.8 (2.6) a	0.0 (0.0) a	0.0 (0.0) a
Twinflower	0.1979	1.7 (5.3) a	10.8 (21.2) a	15.8 (20.6) a
Woodland grass	0.2844	90.0 (15.6) a	88.3 (27.6) a	75.8 (19.0) a
Shining clubmoss	0.3811	0.0 (0.0) a	2.5 (7.9) a	0.0 (0.0) a
Rubus spp.	0.4179	16.7 (24.2) a	32.5 (28.5) a	31.7 (35.3) a
Sweetfern	0.0777	0.0 (0.0) a	0.0 (0.0) a	8.3 (15.7) a
Greenish flowered pyrola	0.6120	0.8 (2.6) a	0.8 (2.6) a	0.0 (0.0) a

1 Underlined values represent $P \leq 0.05$.
2 Means within a row followed by the same letter are not significantly different at the 0.05 level using the Sheffe test.

Soil and Vegetation Variables

The discriminant analysis produced two canonical discriminant functions (Table 21). Table 22 shows the relative importance of each function. Function 1 accounted for 58.69% of the variance, both were highly correlated with the ELT's (0.9999 and 0.9998 respectively), and the chi-squared statistics were significant. The combination of soil and vegetation variables produced a much more equitable sharing of the discrimination. This is also apparent from the territorial map (Figure 15). The centroids are evenly separated along both functions and there is a very cohesive grouping around each centroid. A matrix of pairwise F ratios and their significances (Table 23) showed that the combination of soil and vegetation variables produced significant differences between centroids.

Percent correct classification (Table 24) was determined using the derived classification functions (Table 25). The SPSS program discriminant and "U" technique produced 100.0% and 83.3% correct classification respectively. The combination of soil and vegetation variables increased correct classification by 16.6% over the soil variables alone and 26.6% over the vegetation variables alone. Pregitzer and Barns (1984)

Table 21. Unstandardized and standardized canonical disriminant function coefficients for soil and vegetation variables used to discriminate the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

	Coefficients for Function 1		Coefficients for Function 2	
Variable	Unstandardized	Standardized	Unstandardized	Standardized
% Clay, E Horizon	-3.544202	-6.41589	7.785222	14.09336
OM, E Horizon (kg/ha)	-0.001658	-19.98646	0.000194	2.33885
Ph, Bhs Horizon	-11.98095	-18.18456	-4.455353	-6.76229
K, Bhs Horizon (kg/ha)	0.093869	4.44947	0.084909	4.02476
Depth, Bs Horizon (cm)	1.276435	12.44571	0.869528	8.47823
OM, Bs Horizon (kg/ha)	-0.000222	-3.24836	-0.000049	-0.72066
Ph, C Horizon	-4.048246	-6.33408	-0.152091	-0.23796
% Silt, C Horizon	0.457284	2.62692	-0.349000	-2.00490
K, Oi Layer	-1.697352	-6.04646	-2.409817	-8.58448
K, Oa Layer	0.604307	8.40740	0.745803	10.37597
Ground pine	55.33056	20.49016	32.32168	11.96946
Beaked hazel	-46.97096	-13.06700	-31.16880	-8.67096
Viola spp.	123.2104	24.63249	96.42759	19.27804
Bunchberry	29.24598	9.70790	-2.359868	-0.78336
Rosey twisted stalk	422.9156	15.76105	25.14578	0.93710
Fly honeysuckle	404.0750	29.69657	65.52324	4.81545
Solomon's seal	84.83670	9.81117	66.25627	7.66240
Spreading dogbane	115.2981	5.96312	41.75614	2.15959
Bush honeysuckle	-10.54207	-2.10419	16.07865	3.20932
Maidenhair fern	309.5503	4.70963	-147.9439	-2.25090
Cow wheat	23.09730	3.90789	-31.14223	-5.26908
Field pussytoes	-1403.797	-21.35799	-336.4865	-5.11944
Site Index (ft)	-15.05226	-29.89918	4.577569	9.09280
(Constant)	1578.338		-160.8979	

Table 22. Statistics for evaluating the degree of association between Ecological Land Types and canonical discriminant functions, and the significance of residual discrimination for soil and vegetation variables on the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

Function	Eigenvalue	Percent of Variance	Cumulative Percent	Canonical Correlation	:	After Function	Wilks' Lambda	Chi-squared	D.F.	Significance
					:	0	0.0000001	260.56	46	0.0000
1	4096.26260	58.69	58.69	0.9998780	:	1	0.0003468	127.47	22	0.0000
2	2882.89777	41.31	100.00	0.9998266	:					

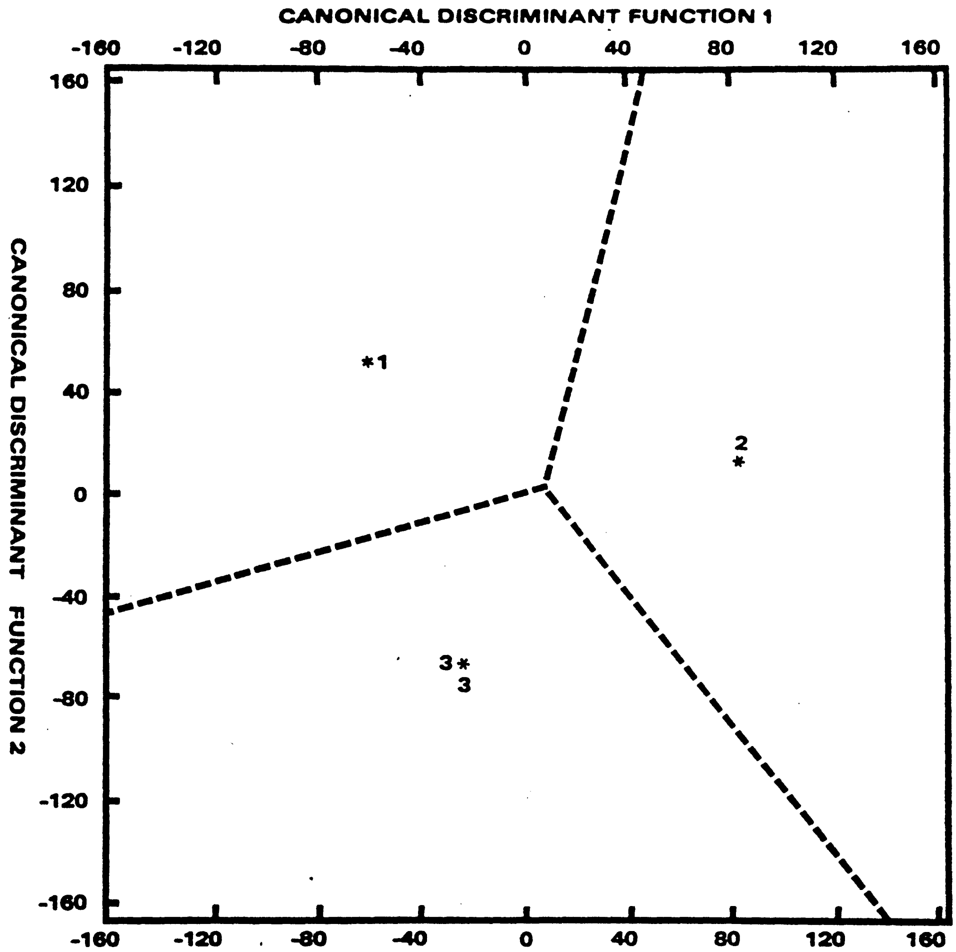


Figure 15. Territorial map showing Ecological Land Type centroids (*) and plot clusters using soil and vegetation variables for the Padus (1), Pence (2), and Vilas (3) ELT's in northeastern Wisconsin.

Table 23. F statistics and significances between pairs of Ecological Land Types in northeastern Wisconsin using soil and vegetation variables. Each F statistic has 23 and 5 degrees of freedom.

	Padus	Pence
Pence	868.32 0.0000	
Vilas	640.36 0.0000	767.15 0.0000

Table 24. Classification results from SPSS program Discriminant and validation results using the "U" method of error estimation for soil and vegetation variables on the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

Classification results from SPSS program Discriminant

Actual ELT	No. of cases	Predicted ELT Membership Padus	Pence	Vilas
Padus	10	10 (100.0%)	0 (0.0%)	0 (0.0%)
Pence	10	0 (0.0%)	10 (100.0%)	0 (0.0%)
Vilas	10	0 (0.0%)	0 (0.0%)	10 (100.0%)

Percent of ELT's correctly classified = 100.0%

Validation results using the "U" method of error estimation

Actual ELT	No. of cases	Predicted ELT Membership Padus	Pence	Vilas
Padus	10	9 (90.0%)	1 (10.0%)	0 (0.0%)
Pence	10	1 (10.0%)	7 (70.0%)	2 (20.0%)
Vilas	10	0 (0.0%)	1 (10.0%)	9 (90.0)

Percent of ELT's correctly classified = 83.3%

Table 25. Classification function coefficients for soil and vegetation variables used to classify the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

Variable	Padus	Pence	Vilas
% Clay, E Horizon	7479.119	6692.973	6413.337
OM, E Horizon (kg/ha)	2.753495	2.510481	2.673849
pH, Bhs Horizon	18644.85	17100.70	18780.99
K, Bhs Horizon (kg/ha)	-136.0320	-125.7429	-143.1739
Depth, Bs Horizon (cm)	-1911.174	-1760.948	-1973.654
OM, Bs Horizon (kg/ha)	0.354311	0.324550	0.352790
pH, C Horizon	6644.460	6073.744	6526.030
% Silt, C Horizon	-832.7475	-755.0318	-774.8782
K, Oi Layer (kg/ha)	2267.138	2112.728	2502.531
K, Oa Layer (kg/ha)	-829.7827	-770.7503	-899.9618
Ground pine	-83660.99	-76954.76	-85716.88
Beaked hazel	70152.34	64594.29	72350.87
Viola spp.	-181044.3	-166995.5	-188593.5
Bunchberry	-48417.51	-44169.32	-47141.70
Rosey twisted stalk	-687013.2	-627726.0	-675765.6
Fly honeysuckle	-647238.8	-592094.2	-641534.3
Solomon's seal	-124966.6	-115288.3	-130147.7
Spreading dogbane	-179765.7	-164865.2	-180939.8
Bush honeysuckle	20744.25	18661.99	18434.14
Maidenhair fern	-538619.1	-489205.7	-510174.8
Cow wheat	-44398.77	-39984.42	-39833.80
Field pussytoes	2223230.	2035590.	2216637.
Site Index	25645.98	23337.85	24580.73
(Constant)	-1364312.	-1134358.	-1290965.

reported similar increases in correct classification when vegetation was used in conjunction with topography and soil characteristics. This showed that there was an increased efficiency when soils and vegetation were combined into one classification system. Padus and Vilas had 90.0% correct classification, but Pence only had 70.0%. All three data sets have shown that the two ELT's at the extremes of the productivity gradient (Padus and Vilas) have had the highest percent correct classification, but the Pence was intermediate and consistently had the lowest correct classification.

ANOVA and Scheffe tests (Table 26) showed that of the 11 soil and 12 vegetation variables selected in the stepwise procedure, 7 soil discriminator variables had significant ($P \leq 0.05$) differences, while only 2 vegetation discriminator variables had significant differences. This demonstrates that the vegetation variables were important in discriminating between the three ELT's, but that large standard deviations reduced the significance of the differences.

Table 26. Means, standard deviations (in parentheses), and F statistics for soil and vegetation discriminator variables presented in order of stepwise inclusion for the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

Variable	F Prob.	Padus	Pence	Vilas
Site Index (m)	0.0000[1]	18.4 (0.9) a[2]	16.7 (0.4) b	16.5 (0.4) b
% Clay, E Horizon	0.0043	8.2 (2.8) a	6.3 (1.1) ab	5.2 (1.0) b
Viola spp.	0.0007	42.5 (19.4) a	36.7 (24.0) a	5.8 (15.7) b
K, Oi Layer (kg/ha)	0.3422	14.0 (4.3) a	11.7 (3.3) a	12.9 (3.0) a
Fly honeysuckle	0.2233	1.7 (3.5) a	7.5 (10.7) a	4.2 (5.9) a
K, Oa Layer (kg/ha)	0.0188	64.2 (15.1) ab	72.8 (14.5) a	53.9 (11.8) b
pH, Bhs Horizon	0.0016	5.1 (0.1) a	4.8 (0.2) b	4.9 (0.1) b
Field pussytoes	0.3811	0.0 (0.0) a	0.0 (0.0) a	0.8 (2.6) a
Beaked hazel	0.0976	40.8 (25.3) a	35.0 (29.1) a	61.7 (28.9) a
Ground pine	0.3742	45.0 (42.7) a	36.7 (40.3) a	21.7 (24.8) a
Solomon's seal	0.0137	16.7 (18.0) a	1.7 (3.5) b	3.3 (8.1) ab
Depth, Bs Horizon (cm)	0.0063	35.8 (12.0) a	25.4 (9.2) ab	20.9 (7.5) b
Bush honeysuckle	0.1872	3.3 (7.0) a	18.3 (21.8) a	17.5 (25.9) a
Bunchberry	0.1781	11.7 (20.9) a	40.0 (37.2) a	28.3 (38.5) a
K, Bhs Horizon (kg/ha)	0.2341	88.7 (47.3) a	92.9 (63.5) a	58.9 (21.7) a
Spreading dogbane	0.0606	0.0 (0.0) a	0.0 (0.0) a	5.0 (9.0) a
Rosey twisted stalk	0.8473	1.7 (5.3) a	0.8 (2.6) a	0.8 (2.6) a
OM, E Horizon (kg/ha)	0.1546	24900 (18400) a	14200 (7300) a	18200 (6500) a
pH, C Horizon	0.0375	5.1 (0.1) a	5.1 (0.2) a	5.2 (0.1) a
Maidenhair fern	0.3811	0.8 (2.6) a	0.0 (0.0) a	0.0 (0.0) a
OM, Bs Horizon (kg/ha)	0.0239	52200 (14000) a	44900 (16900) ab	33100 (12700) b
% Silt, C Horizon	0.2431	9.9 (5.7) a	8.4 (6.3) a	5.6 (5.1) a
Cow wheat	0.2456	0.0 (0.0) a	0.8 (2.6) a	11.7 (29.2) a

1 Underlined values represent $P \leq 0.05$.
2 Means within a row followed by the same letter are not significantly different at the 0.05 level using the Scheffe test.

Post-Cut Vegetation

The discriminant analysis produced two canonical discriminant functions (Table 27). Table 28 shows the relative importance of each function. Function 1 accounted of 75.33% of the variance, both were highly correlated with the ELT's (0.9998 and 0.9994 respectively), and the chi-squared statistics were significant. The territorial map (Figure 16) shows the influence of each function on the separation of ELT centroids. A matrix of pairwise F ratios and their significances (Table 29) showed that the ELT centroids were not significantly different at the $P \leq 0.05$ level, but were at the $P \leq 0.10$ level. There are two possible reasons for this and unfortunately the contribution of one can not be separated from the other. The first reason is that the post-cut vegetation variables were not effective in discriminating between the three ELT's. The second reason is that the reduction in sample size from 30 to 17 plots reduced the sensitivity of the analysis. Since there were significant differences at the $P \leq 0.10$ level, it would seem reasonable that if the sample size had been maintained at the original level (30) the post-cut vegetation variables would have been able to separate the ELT centroids at the $P \leq 0.05$ level.

Table 27. Unstandardized and standardized canonical discriminant function coefficients for post-cut vegetation variables used to discriminate the Padus, Pence, Vilas Ecological Land Types in northeastern Wisconsin.

	Coefficients for Function 1		Coefficients for Function 2	
Variable	Unstandardized	Standardized	Unstandardized	Standardized
Wild lily of the valley	34.82051	9.57503	-43.22946	-11.88734
Starflower	56.66445	16.86330	52.44950	15.60893
Large leaf aster	-63.14422	-17.53760	-37.14676	-10.31710
Viola spp.	104.0419	21.45904	41.31983	8.52237
Low sweet blueberry	58.54770	11.32485	22.93527	4.43636
Bunchberry	-68.59130	-22.42639	64.73067	21.16413
Wolf's claw clubmoss	-94.42938	-11.75002	-120.7532	-15.02554
Hawkweed	132.7826	15.69840	86.07581	10.17643
Wintergreen	-71.97379	-17.52929	19.88588	4.84323
Sweetfern	66.03463	4.02770	74.81014	4.56295
Climbing false buckwheat	-8.477458	-2.41924	-18.19609	-5.19267
Field pussytoes	-479.9929	-29.64601	-112.7498	-6.96381
Oxalis	433.9985	14.26688	275.5497	9.05817
Solidago spp.	128.0971	8.76026	7.546123	0.51606
(Constant)	-24.31857		6.745840	

Table 28. Statistics for evaluating the degree of association between Ecological Land Types and canonical discriminant functions, and the significance of residual discrimination for post—cut vegetation variables on the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

Function	Eigenvalue	Percent of Variance	Cumulative Percent	Canonical Correlation	:	After Function	Wilks' Lambda	Chi-squared	D.F.	Significance
					:	0	0.0000004	109.95	28	0.0000
1	2663.69605	75.33	75.33	0.9998123	:	1	0.0011447	50.79	13	0.0000
2	872.56827	24.67	100.00	0.9994275	:					

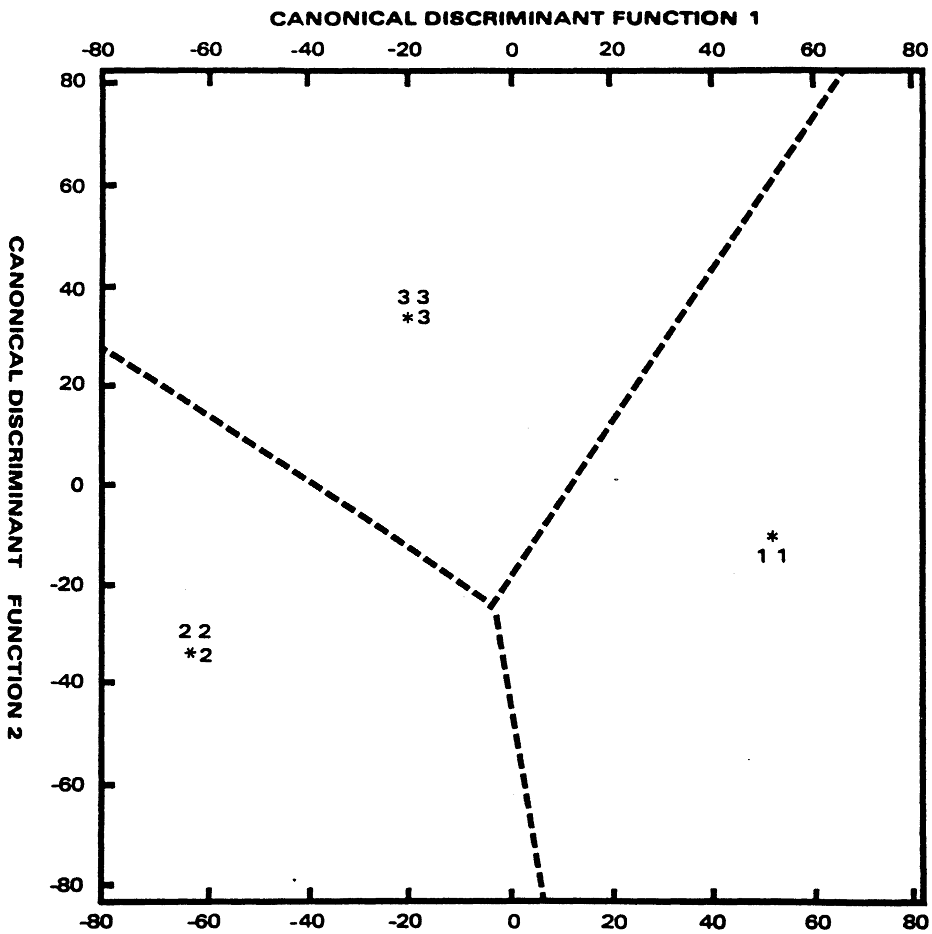


Figure 16. Territorial map showing Ecological Land Type centroids (*) and plot clusters using post-cut vegetation variables for the Padus (1), Pence (2), and Vilas (3) ELT's in northeastern Wisconsin.

Table 29. F statistics and significances between pairs of Ecological Land Types in northeastern Wisconsin using post-cut vegetation variables. Each F statistic has 14 and 1 degrees of freedom.

	Padus	Pence
Pence	178.70 0.0586	
Vilas	118.90 0.0718	78.263 0.0884

Percent correct classification (Table 30) was determined using the derived classification functions (Table 31). The SPSS program discriminant and "U" technique produced 100.0% and 41.2% correct classification respectively. Compared with the pre-cut vegetation discriminator variables there was a 15.5% decrease in correct classification. Again, the decrease could be from a lack of discriminating power of the discriminator variables and/or the reduction in sample size.

ANOVA and Scheffe tests (Table 32) showed an interesting stability in vegetation variables to discriminate the three ELT's after clearcutting. 7 of the 14 post-cut discriminator variables were also selected as discriminator variables in the vegetation and/or soil and vegetation data sets. The first five discriminator variables selected in the stepwise procedure were also selected in the vegetation and/or soil and vegetation data sets. 3 of the 4 post-cut discriminator variables with significant differences also had significant differences prior to clearcutting. This analysis has shown that vegetation variables important in discriminating the three ELT's prior to clearcutting are relatively stable and able to discriminate the three ELT's one growing season after clearcutting.

Table 30. Classification results from SPSS program Discriminant and Validation results using the "U" method of error estimation for post-cut vegetation variables on the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

Classification results from SPSS program Discriminant

Actual ELT	No. of cases	Predicted ELT Membership Padus	Pence	Vilas
Padus	7	7 (100.0%)	0 (0.0%)	0 (0.0%)
Pence	4	0 (0.0%)	4 (100.0%)	0 (0.0%)
Vilas	6	0 (0.0%)	0 (0.0%)	6 (100.0%)

Percent of ELT's correctly classified = 100.0%

Validation results using the "U" method of error estimation

Actual ELT	No. of cases	Predicted ELT Membership Padus	Pence	Vilas
Padus	7	3 (42.8%)	2 (28.6%)	2 (28.6%)
Pence	4	0 (0.0%)	2 (50.0%)	2 (50.0%)
Vilas	6	2 (33.3%)	2 (33.3%)	2 (33.3%)

Percent of ELT's correctly classified = 41.2%

Table 31. Classification function coefficients for post-cut vegetation variables used to classify the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

Variable	Padus	Pence	Vilas
Wild lily of the valley	3554.430	435.1897	-918.5922
Starflower	3379.310	-4254.368	1739.711
Large leaf aster	-4177.225	3885.741	-1371.910
Viola spp.	7156.668	-5714.383	1621.105
Low sweet blueberry	4048.788	-3187.565	919.2061
Bunchberry	-6487.647	82.21243	1385.534
Wolf's claw clubmoss	-4958.765	8457.072	-3757.927
Hawkweed	8547.113	-8573.893	3013.616
Wintergreen	-5857.926	2036.434	197.4243
Sweetfern	3661.021	-5520.066	2378.887
Climbing false buckwheat	-295.4904	1062.124	-525.4798
Field pussytoes	-34606.58	23151.43	-5491.990
Oxalis	27868.70	-27970.58	9516.699
Solidago spp.	9793.306	-5151.192	988.0970
(Constant)	-3119.630	-1521.903	-417.7014

Table 32. Means, standard deviations (in parentheses), and F statistics for post-cut vegetation discriminator variables presented in order of stepwise inclusion for the Padus, Pence, and Vilas Ecological Land Types in northestern Wisconsin.

Variable	F Prob	Padus	Pence	Vilas
Viola spp.	0.0039[1]	60.7 (21.4) a[2]	45.8 (25.9) ab	13.9 (15.5) b
Wintergreen	0.0170	0.0 (0.0) a	6.3 (12.5) ab	43.1 (39.6) b
Bunchberry	0.2680	6.0 (12.5) a	27.1 (38.1) a	36.1 (44.0) a
Field pussytoes	0.1728	1.2 (3.2) a	8.3 (11.8) a	1.4 (3.4) a
Large leaf aster	0.0137	81.0 (20.3) a	89.6 (4.2) a	36.1 (40.7) b
Starflower	0.0555	29.8 (24.0) a	0.0 (0.0) a	51.4 (42.3) a
Oxalis	0.4146	2.4 (4.1) a	2.1 (4.2) a	0.0 (0.0) a
Low sweet blueberry	0.0059	6.0 (15.7) a	0.0 (0.0) a	41.7 (27.4) b
Hawkweed	0.1503	10.7 (15.0) a	14.6 (14.2) a	0.0 (0.0) a
Wolf's claw clubmoss	0.2636	4.8 (6.6) a	16.7 (23.6) a	4.2 (7.0) a
Solidago spp.	0.2446	6.0 (10.4) a	0.0 (0.0) a	0.0 (0.0) a
Wild lily of the valley	0.4337	84.5 (19.5) a	64.6 (27.5) a	68.1 (34.7) a
Sweetfern	0.4266	0.0 (0.0) a	0.0 (0.0) a	4.2 (10.2) a
Climbing false buckwheat	0.1132	35.7 (41.6) a	22.9 (18.5) a	0.0 (0.0) a

1 Underlined values represent $P \leq 0.05$.
2 Means within a row followed by the same letter are not significantly different at the 0.05 level using the Scheffe test.

Conclusions

Discriminant analysis was effective in discriminating between the Padus, Pence, and Vilas ELT's. The best results were obtained with a combination of soil and vegetation characteristics. This produced a correct classification of 83.3%, compared to 66.7% for the soil and 56.7% for the vegetation data sets. The ability of vegetation to discriminate between ELT's one year after clearcutting was reduced to 41.2% correct classification because of the site disturbance and a reduction in sample size. Comparisons between pre-cut and post-cut vegetation species selected as discriminator variables showed a surprising stability following disturbance.

ANOVA and Scheffe tests showed that there were significant differences in soil-site characteristics between the three ELT's. The stepwise selection and tests of significance demonstrated a productivity gradient from Padus (high), Pence, and Vilas (low). Few significant differences were associated with the vegetation variables because of large standard deviations.

OBJECTIVE 2

The second objective was to evaluate the level of competing vegetation on the three ELT's.

Statistical Methods

This was accomplished by using ANOVA to test for significant differences in the number of peg board dots visually obstructed by vegetation.

Results and Discussion

Results of the ANOVA showed that there were no significant differences (F prob.=0.2344) in the amount of visual obstruction for the three ELT's. Table 33 shows that the Padus ELT had the greatest average percentage of dots obstructed, Pence was lowest, and Vilas was intermediate. There were two problems with this analysis. First, the reduction in sample size from 30 to 17 plots reduced the sensitivity of the statistical analysis. Second, one growing season was not sufficient time to establish differences.

Hopefully, this procedure can be repeated after the second growing season. Expected results would show a gradient in competing vegetation similar to the

Table 33. Means, standard deviations, and ranges for the percentage of dots visually obstructed by vegetation on the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

ELT	# of plots	Means	Standard deviations	Minimum	Maximum
Padus	7	40.5	20.3	14.3	71.5
Pence	4	15.6	9.4	6.1	26.8
Vilas	6	29.1	29.0	4.7	78.2

productivity gradient that has been established, with the Padus high in competing vegetation, Vilas low, and Pence intermediate.

Conclusions

This method of obtaining a measure of competing vegetation is quick, easy, effective and deserves a more thorough field testing. Unfortunately, the large reduction in sample size has reduced the validity in this study.

OBJECTIVE 3

The third objective was to determine if there was a significant difference in red pine seedling survival and growth on the three ELT's.

Statistical Methods

The ANOVA was used to test for significant differences in the average survival of seedlings and the analysis of covariance (ANCOVA) was used to test for significant differences in diameter and height growth. ANCOVA makes adjustments for differences in initial seedling size which may influence growth .

Results and Discussion

The analysis found no significant differences in the average number of red pine seedlings surviving the first growing season (Table 34). The number of dying seedlings was added to the number of dead and subtracted from the total number planted per plot to provided a total number of visibly healthy seedlings per plot. There were no significant differences in the average number of healthy seedlings after the first growing season.

Analysis of covariance showed that there was a significant difference in diameter growth between the

Table 34: Means, standard deviations (in parentheses), and F statistics for survival and growth of red pine seedlings on the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

Variable	F Prob	Padus	Pence	Vilas
Survival 1 (20/plot - # dead)	0.611	19.0 (0.8) a[1]	19.4 (1.0) a	19.1 (1.0) a
Survival 2 (20/plot - # dead and dying)	0.817	16.8 (1.7) a	17.1 (3.0) a	17.5 (2.5) a
Diameter Growth (mm)	0.000[2]	0.6 (0.4) ab	0.5 (0.4) a	0.7 (0.5) b
Height Growth (cm) (Shoot)	0.569	3.2 (1.8) a	3.2 (2.1) a	3.4 (1.9) a
Height Growth (cm) (Needle length)	0.196	5.0 (1.9) a	5.3 (1.6) a	5.5 (3.8) a
Height Growth (cm) (Shoot and needles)	0.158	8.4 (2.9) a	8.7 (2.8) a	9.1 (4.1) a

1 Means within a row followed by the same letter are not significantly different at the 0.05 level using the Scheffe test.

2 Underlined values represent $P \leq 0.05$.

Padus, Pence, and Vilas ELT's. Vilas was significantly higher than the Pence, while Padus was intermediate and non significant when compared with the Vilas and Pence. It is difficult to interpret the importance of this difference because it was only a 0.2 mm difference in the average diameter growth between the Vilas and Pence. Also, one growing season is not much time to establish significant differences. Strothmann (1967) found that different levels of light and moisture did not produce significant differences in red pine seedling growth until the second year. For this reason, and the fact that height growth and survival were not significantly different between the three ELT's, caution was used not to place to much importance on the significant difference in diameter growth.

Conclusions

The productivity gradient from Padus (high), Pence, and Vilas (low) that was established in the discriminant analysis was not reflected in the growth and survival of red pine seedlings after one growing season. The Padus ELT should produce the best seedling growth and survival in following years, but this may be offset by more competing vegetation. At least one more year is needed to evaluate seedling differences between the three ELT's.

OBJECTIVE 4

The fourth objective was to evaluate how the Padus, Pence, and Vilas ELT's differed in factors influencing red pine seedling survival and growth.

Statistical Methods

Graphical representation and multivariate analysis of variance (MANOVA) on a repeated measures design were used to evaluate differences in seedling characteristics such as height, diameter, and moisture status and site characteristics such as soil water tension, total soil nitrogen, soil ammonium, and soil nitrate concentrations. Data was obtained from the six plot subsample described in the general methods section.

Results and Discussion

Figure 17 shows the graphical representation of the height measurements. Means and standard deviations are provided in appendix 4. Initial ranking from tallest to shortest was Pence, Vilas, and Padus. This ranking was maintained throughout the measurement period. The MANOVA procedure found significant differences in height with respect to ELT, ELT by time, and time (Table 35). This showed that during the first growing season highly

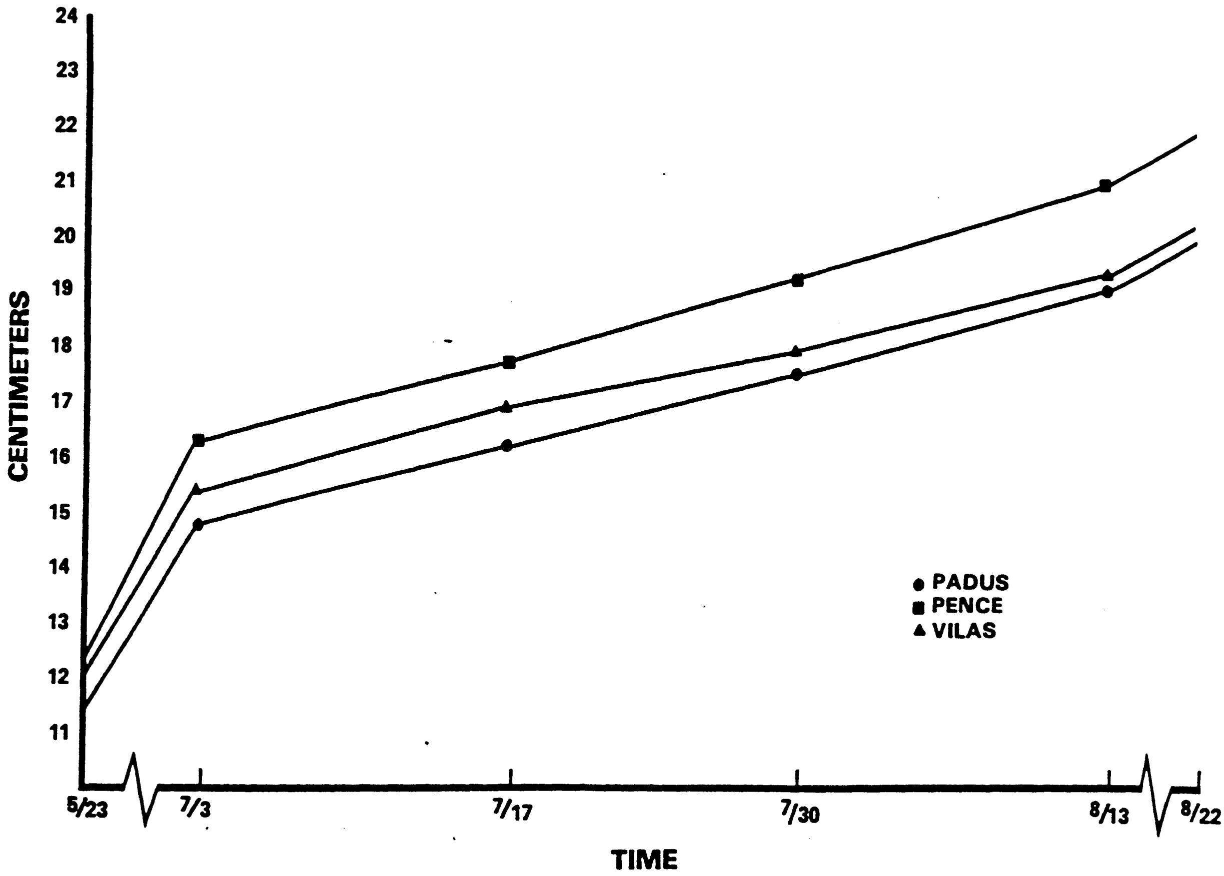


Figure 17. Average height of red pine seedlings during the July and August 1985 growing period on the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

Table 35. F statistics using analysis of variance with repeated measures for factors influencing red pine seedling survival and growth on the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

Factors	Effects	F probability
Height		
	ELT	0.036
	ELT by Time	0.000
	Time	0.000
Diameter		
	ELT	0.093
	ELT by Time	0.009
	Time	0.000
Needle water tension		
	ELT	0.000
	ELT by Time	0.039
	Time	0.337
Total soil nitrogen		
	ELT	0.368
	ELT by Time	0.190
	Time	0.058
Soil ammonium		
	ELT	0.011
	ELT by Time	0.367
	Time	0.034
Soil nitrate		
	ELT	0.036
	ELT by Time	0.492
	Time	0.877
Soil water tension		
	ELT	0.004
	ELT by Time	0.092
	Time	0.145
Soil temperature		
	ELT	0.004
	ELT by Time	0.015
	Time	0.000

significant differences in height were associated with time, and significant differences were associated with ELT.

Figure 18 shows the graphical representation of the diameter measurements. The initial ranking from largest to smallest was Pence, Vilas, and Padus, the same as for seedling height. This ranking was maintained until early August when the average Padus diameter was larger than the average Vilas diameter, Pence was still the largest. The MANOVA procedure found significant differences in diameter with respect to ELT by time and time, but there were no significant differences in diameter with respect to ELT (Table 35). Again, this demonstrates that differences in seedling growth during the first growing season were primarily associated with time and not ELT.

Figure 19 shows the graphical representation of the seedling water status measurements. Initial ranking showed that Pence had the greatest seedling water tension followed by Padus and Vilas. By the second measurement (July 17) seedlings on the Vilas ELT had the greatest needle water tension followed by Pence and Padus. This ranking was maintained through the rest of the measurement period. The MANOVA procedure found significant differences in seedling water status

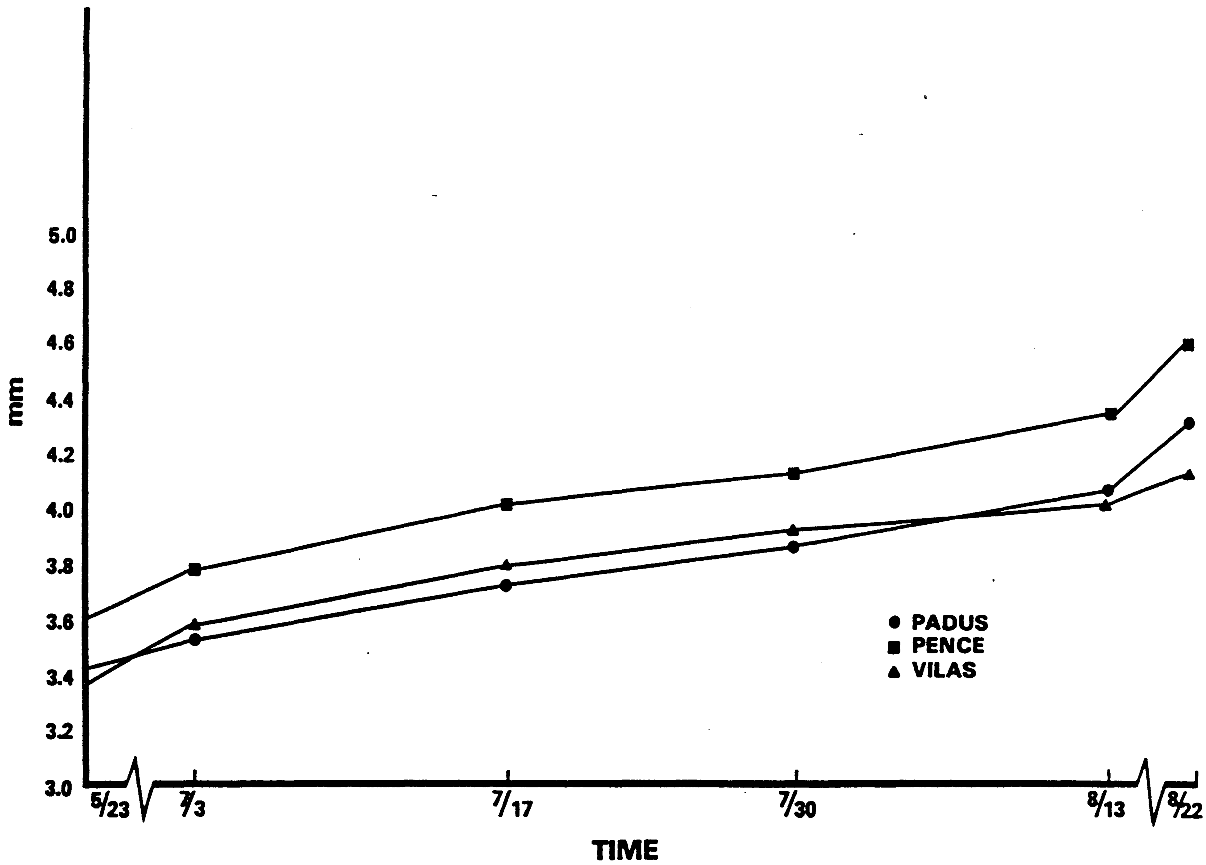


Figure 18. Average diameter of red pine seedlings during the July and August 1985 growing period on the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

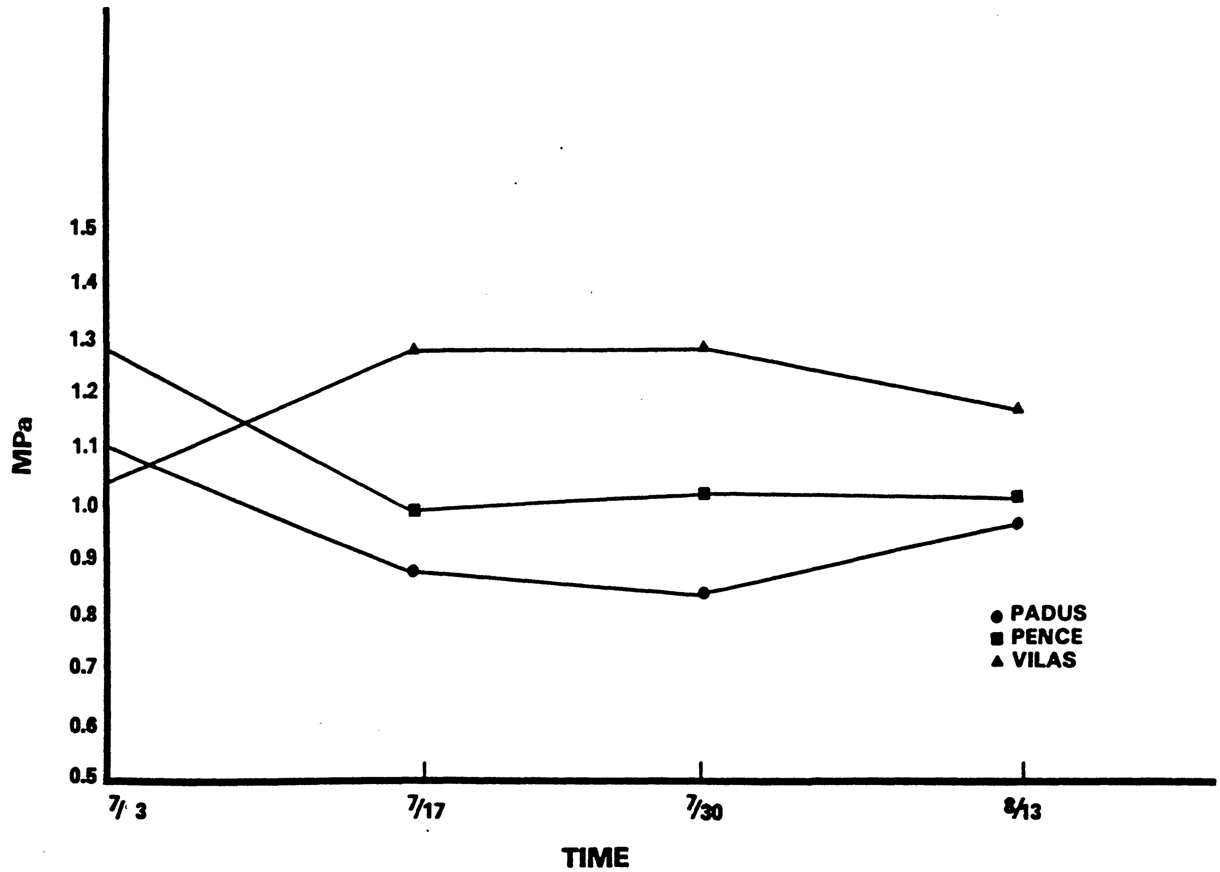


Figure 19. Average needle water tension of red pine seedlings during the July and August 1985 growing period on the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

associated with ELT and ELT by time, but there were no significant differences in seedling water status with respect to time (Table 35). This demonstrates that significant differences in seedling water status were associated with ELT, and graphing the results showed that the Vilas ELT seedlings had higher needle water tension through most of the growing season. This is because of the lower water holding capacity associated with the sandier Vilas soil. Table 14 shows that when compared with the Padus ELT the Vilas ELT had significantly lower % clay in the E and C horizon, and significantly lower % silt in the Bs horizon.

Figure 20 shows the graphical representation of the soil water tension measurements. Initial ranking showed that Vilas soil water was under the most tension followed by Pence and Padus. This ranking was maintained throughout the measurement period. The MANOVA procedure found significant differences in soil water tension associated with ELT, but not with ELT by time or time (Table 35). This analysis showed that there was a significant difference in soil water tension and the graphical representation clearly showed that the soil water tension was much greater on the Vilas ELT. This supports the previous results showing that seedling needle water tension was greater on the Vilas ELT.

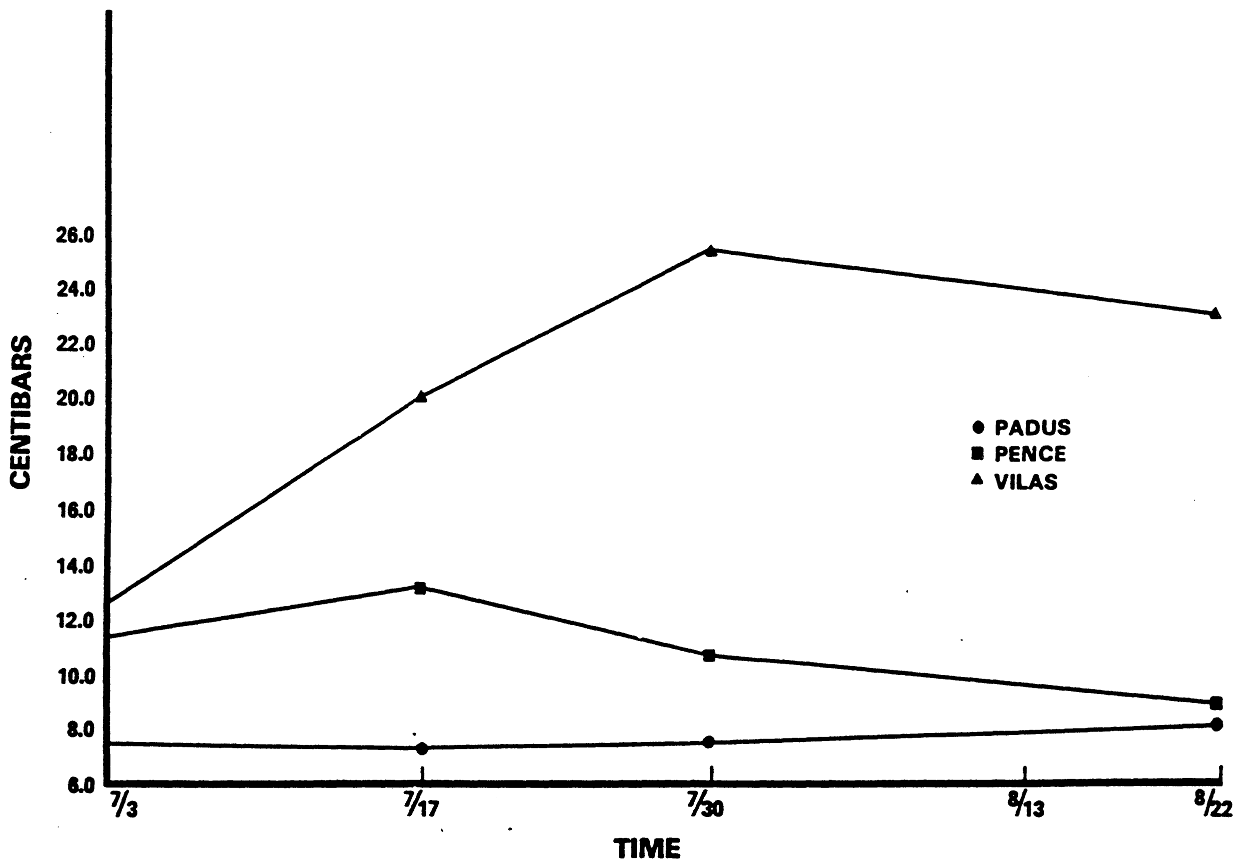


Figure 20. Average soil water tension during the July and August 1985 growing period on the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

Figure 21 shows the graphical representation for the total nitrogen measurements. The Vilas ELT had the lowest total nitrogen throughout the measurement period, while the Padus and Pence changed first and second ranking twice. The MANOVA procedure found no significant differences in total nitrogen with respect to ELT, ELT by time, and time (Table 35). Figures 22 and 23 show the same general trends for ammonium and nitrate concentrations, with Vilas having the lowest inorganic nitrogen throughout the measurement period. For both ammonium and nitrate there were significant differences associated with ELT, and time was significant for ammonium (Table 35). The consistently lower levels of nitrogen on the Vilas ELT should be an important factor in site fertility and red pine seedling growth.

Figure 24 shows the graphical representation of the soil temperature measurements. Table 35 shows that the MANOVA procedure found ELT, ELT by time, and time significant with respect to soil temperature. The first two sets of measurements (July 3 and 17) were taken during the post-dawn measurements and reflect the time of measurement instead of differences between ELT's. Because of the order of post-dawn field work, Vilas plots were measured early in the morning and Pence plots

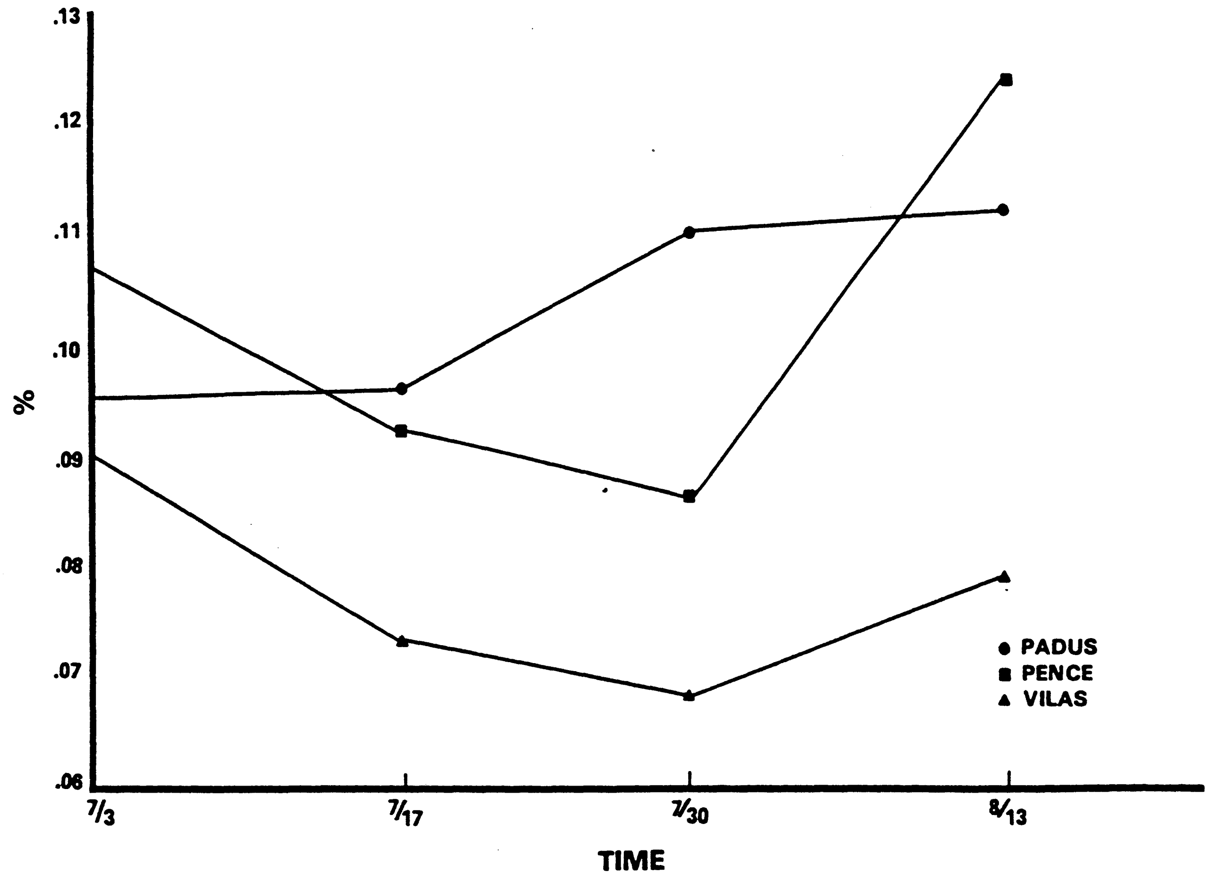


Figure 21. Average total soil nitrogen during the July and August 1985 growing period on the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

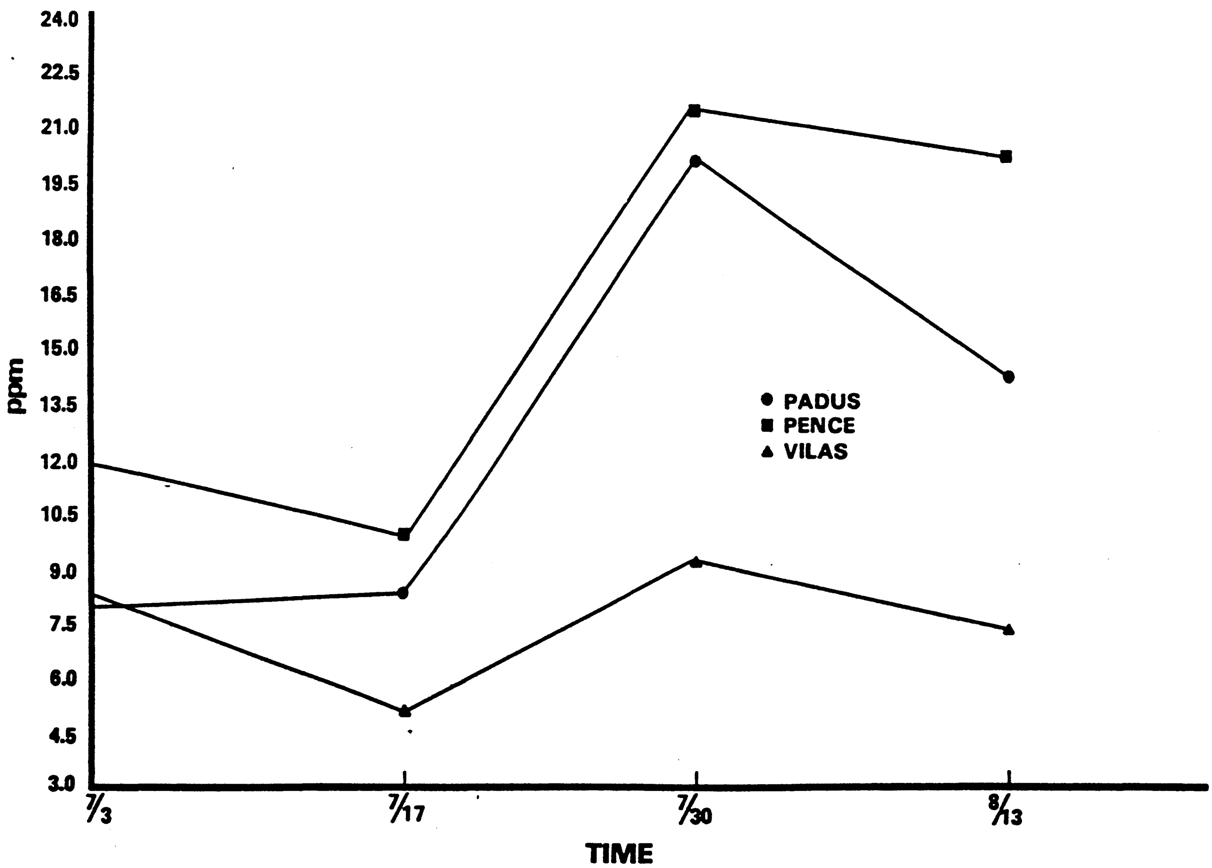


Figure 22. Average soil ammonium during the July and August 1985 growing period on the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

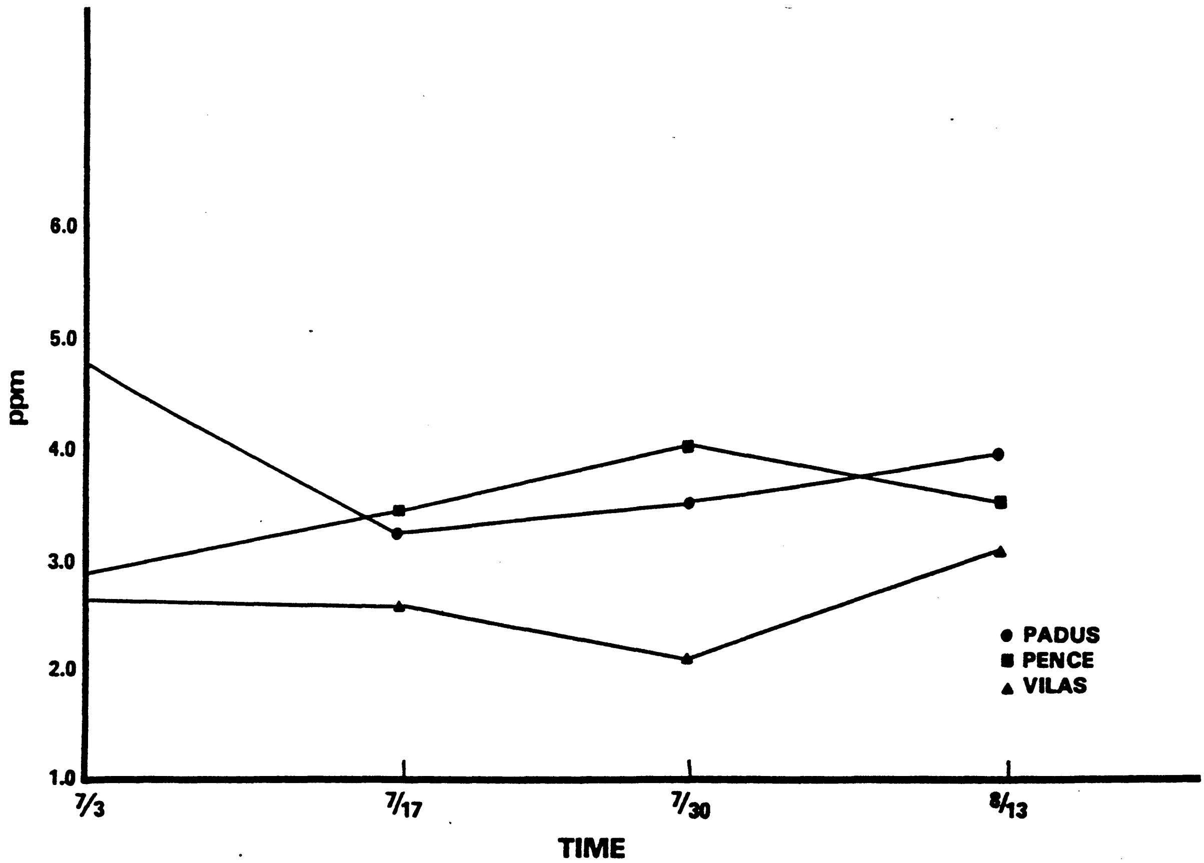


Figure 23. Average soil nitrate during the July and August 1985 growing period on the Padus, Pence, and Vilas Ecological Land Types in Northeastern Wisconsin.

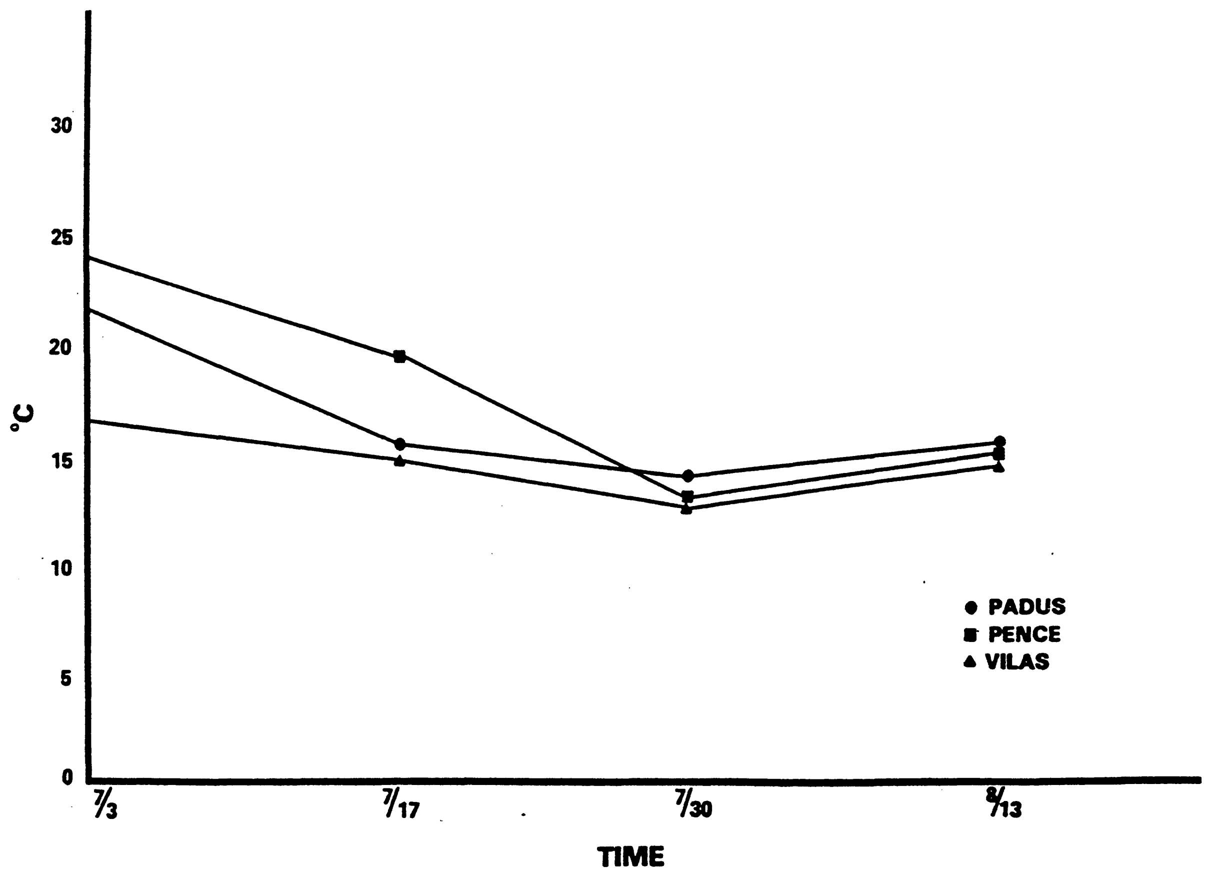


Figure 24. Average soil temperature during the July and August 1985 growing period on the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

closer to noon, with Padus in the middle. This is clearly reflected in the July 3 and 17 data sets. This problem was recognized in the field and corrected during the July 30 and August 13 measurements. For these last two data sets soil temperatures were all pre-dawn measurements and clearly show a tight grouping between the three ELT's. Because of this inconsistency, little importance was placed on the significant differences associated with soil temperatures.

Conclusions

During the first growing season differences in red pine seedling height and diameter growth were primarily associated with time and not ELT. This was not surprising because of the determinate growth pattern of red pine, which established the 1985 growth potential while in uniform nursery conditions the previous summer.

Measurements of water relations showed that the sandiest soil (Vilas) had the greatest soil water tension and needle water tension. Because of the poorer water holding capacity of the Vilas ELT the seedlings were under more water stress. Total nitrogen, ammonium, and nitrate were consistently lower on the Vilas ELT. The lower levels of nitrogen and poorer water relations measured on the Vilas ELT during the 1985 season should be reflected in less growth in 1986.

STUDY CONCLUSIONS

Both the Ecological Land Type and Habitat Type classification systems used in northeastern Wisconsin have a wide range of forest productivity. By matching an ELT with the habitat type that represents the central concept for that ELT, we were able to reduce the variability and increase the statistical sensitivity of the analysis. The best discriminant model used a combination of soil and vegetation discriminator variables. This demonstrates that the most effective method of identifying ecosystems in northeastern Wisconsin is to incorporate both soils and vegetation into one classification system. This classification refinement can increase the validity of comparisons between red pine responses after conversion.

This study was not able to demonstrate differences in red pine seedling responses because of the short time frame. One growing season was not sufficient time for seedlings or competing vegetation to express the site differences found in the discriminant analysis and analysis of variance.

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Appendix 1. Soil physical and chemical parameters used in the discriminant analysis.

pH of E horizon
depth of E horizon, cm
available phosphorus of E horizon, kg/ha
available potassium of E horizon, kg/ha
exchangeable calcium of E horizon, kg/ha
exchangeable magnesium of E horizon, kg/ha
total nitrogen of E horizon, kg/ha
% clay in E horizon
% silt in E horizon
organic matter in E horizon, kg/ha
SMP buffering value of E horizon

pH of Bhs horizon
depth of Bhs horizon, cm
available phosphorus of Bhs horizon, kg/ha
available potassium of Bhs horizon, kg/ha
exchangeable calcium of Bhs horizon, kg/ha
exchangeable magnesium of Bhs horizon, kg/ha
total nitrogen of Bhs horizon, kg/ha
% clay in Bhs horizon
% silt in Bhs horizon
organic matter in Bhs horizon, kg/ha
SMP buffering value of Bhs horizon

pH of Bs horizon
depth of Bs horizon, cm
available phosphorus of Bs horizon, kg/ha
available potassium of Bs horizon, kg/ha
exchangeable calcium of Bs horizon, kg/ha
exchangeable magnesium of Bs horizon, kg/ha
total nitrogen of Bs horizon, kg/ha
% of clay in Bs horizon
% of silt in Bs horizon
organic matter in Bs horizon, kg/ha
buffering value of Bs horizon

pH of C horizon
depth of C horizon, cm
available phosphorus of C horizon, kg/ha
available potassium of C horizon, kg/ha
exchangeable calcium of C horizon, kg/ha
exchangeable magnesium of C horizon, kg/ha
total nitrogen of C horizon, kg/ha
% of clay in C horizon
% of silt in C horizon
organic matter in C horizon, kg/ha
SMP buffering value of C horizon

Appendix 1. Continued.

total phosphorus in forest floor Oi+Oe layer, kg/ha
total potassium in forest floor Oi+Oe layer, kg/ha
total calcium in forest floor Oi+Oe layer, kg/ha
total magnesium in forest floor Oi+Oe layer, kg/ha
total nitrogen in forest floor Oi+Oe layer, kg/ha

total phosphorus in forest floor Oa layer, kg/ha
total potassium in forest floor Oa layer, kg/ha
total calcium in forest floor Oa layer, kg/ha
total magnesium in forest floor Oa layer, kg/ha
total nitrogen in forest floor Oa layer, kg/ha

Appendix 2. Vegetative ground flora used in the discriminant analysis.

Barren strawberry	Waldsteinia fragarioides (Michx.) Tratt.
Beaked hazel	Corylus cornuta Marsh.
Beech fern	Thelypteris phegopteris (L.) Slosson.
Blue cohosh	Caulophyllum thalictroides (L.) Michx.
Bracken fern	Pteridium aquilinum (L.) Kuhn.
Bunchberry	Cornus canadensis L.
Bush honeysuckle	Diervilla lonicera Mill.
Canada blueberry	Vaccinium myrilloides Michx.
Carex spp.	
Climbing false buckwheat	Polygonum scandens L.
Common strawberry	Fragaria virginiana Duchesne.
Cow-wheat	Melampyrum lineare Desr.
Downy yellow violet	Viola pubescens Ait.
False Solomon's seal	Smilacina racemosa (L.) Desf.
Field pussytoes	Antennaria neglecta Grenne.
Flat topped white aster	Aster umbellatus Mill.
Fly honeysuckle	Lonicera canadensis Marsh.
Fragrant bedstraw	Galium triflorum Michx.
Goldthread	Coptis trifolia (L.) Salisb.
Greenish-flowered pyrola	Pyrola virens Schweigg.
Ground cedar	Lycopodium tristachyum Pursh.
Ground pine	Lycopodium obscurum L.
Hairy honeysuckle	Lonicera hirsuta Eat.
Hawkweed	Hieracium spp.
Large leaf aster	Aster macrophyllus L.
Low sweet blueberry	Vaccinium angustifolium Ait.
Maidenhair fern	Adiantum pedatum L.
Meadow rue	Thalictrum dioicum L.
Oak fern	Gymnocarpium dryopteris (L.) Newm.
Partridge-berry	Mitchella repens L.
Pea	Lathyrus spp.
Pipsissewa	Chimaphila umbellata (L.) Bart.
Pyrola	Pyrola spp.
Rosey twisted stalk	Streptopus roseus Michx.
Round lobed hepatica	Hepatica americana (DC.) Ker.
Rubus spp.	
Serviceberry	Amelanchier spp.
Sessile bellwort	Uvularia sessilifolia L.
Shining clubmoss	Lycopodium lucidulum Michx.
Smooth hawksbeard	Crepis capillaris (L.) Wallr.
Solomon's seal	Polygonatum biforum (Walt.) Ell.
Spinulose shield fern	Dryopteris spinulosa (O.F. Mull.) Watt.

Appendix 2. Continued.

Spreading bogbane	*Apocynum androsaemifolium* L.
Starflower	*Trientalis borealis* Raf.
Sweetfern	*Myrica asplenifolia* L.
Trillium	*Trillium grandiflorum* (Michx.) Salisb.
Twinflower	*Linnaea borealis* L.
Twisted stalk	*Streptopus amplexifolius* Michx.
Viola spp.	
Virgins-bower	*Clematis virginiana* L.
White baneberry	*Actaea alba* (L.) Mill.
White lettuce	*Prenanthes alba* L.
Wild lily of the valley	*Maianthemum canadense* Desf.
Wild sarsaparilla	*Aralia nudicaulis* L.
Wintergreen	*Gaultheria procumbens* L.
Wolf's claw clubmoss	*Lycopodium clavatum* L.
Wood anemone	*Anemone quinquefolia* L.
Wood-betony	*Pedicularis canadensis* L.
Woodland grass	
Yellow beadlily	*Clintonia borealis* (Ait.) Raf.

Appendix 3. Summary stand data for the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

Padus Overstory Stratum

Stand	Species	#/ha	sq m/ha	cu m/ha
1	Paper birch	300	9.3	49.8
	Red maple	450	11.5	55.4
	Total	750	20.8	105.2
2	Paper birch	50	1.1	5.9
	Red maple	150	7.2	26.3
	Balsam fir	100	6.1	14.4
	Total	300	14.4	46.6
3	Paper birch	900	26.7	154.5
	Sugar maple	300	5.8	25.8
	Total	1200	32.5	180.3
4	Paper birch	850	19.1	120.9
	Sugar maple	50	0.7	3.3
	Bigtooth aspen	50	1.4	7.0
	Total	950	21.2	131.2
5	Paper birch	100	3.0	15.5
	Red maple	100	3.0	13.6
	Red pine	200	15.7	79.9
	White spruce	50	2.8	13.3
	Quaking aspen	100	2.9	12.8
	White pine	50	1.7	7.3
	Hophornbeam	50	0.8	1.9
	Total	650	29.9	144.3
	Average	770	23.8	121.5
	Standard deviation	336.5	7.4	49.9

Appendix 3. Continued.

Pence Overstory Stratum

Stand	Species	#/ha	sq m/ha	cu m/ha
1	Paper birch	750	23.0	131.3
	Total	750	23.0	131.3
2	Balsam fir	450	10.5	32.7
	Quaking aspen	150	3.1	16.6
	White pine	50	8.9	23.7
	Total	650	22.5	73.0
3	Bigtooth aspen	1250	41.2	225.7
	Red maple	100	1.5	7.8
	Northern red oak	50	0.7	1.7
	Paper birch	50	1.0	4.9
	Total	1450	44.4	240.1
4	Quaking aspen	100	7.5	25.0
	Red pine	300	12.5	60.1
	Balsam fir	100	2.3	8.9
	White pine	50	2.9	12.2
	White spruce	250	17.2	83.3
	Red maple	50	1.3	6.4
	Total	850	43.7	195.9
5	Red pine	200	21.4	115.9
	Paper birch	50	2.1	8.3
	White pine	150	5.1	12.7
	Balsam fir	100	3.4	18.7
	Total	500	32.0	155.6
	Average	840	33.1	159.2
	Standard deviation	364.7	10.7	63.5

Appendix 3. Continued.

Vilas Overstory Stratum

Stand	Species	#/ha	sq m/ha	cu m/ha
1	White pine	200	19.6	84.8
	White spruce	50	0.7	2.1
	Total	250	20.3	86.9
2	Red maple	350	9.9	49.2
	Northern red oak	150	11.6	89.7
	Paper birch	50	3.9	15.9
	Sugar maple	50	1.1	3.1
	Total	600	26.5	157.9
3	Red pine	450	26.6	156.8
	Paper birch	250	4.2	24.0
	White pine	200	12.5	68.1
	Balsam fir	50	0.7	2.1
	Total	950	44.0	251.0
4	Quaking aspen	1050	18.7	104.1
	Paper birch	50	0.7	4.3
	Total	1100	19.4	108.4
5	Jack pine	300	5.6	20.1
	Quaking aspen	100	2.3	11.9
	Paper birch	100	5.5	24.2
	Total	500	13.4	56.2
	Average	580	24.7	132.1
	Standard deviation	343.9	11.7	76.1

Appendix 3. Continued

Padus Upper Understory Stratum

Stand	Species	#/ha	sq m/ha
1	Balsam fir	800	1.7
	Red maple	200	0.7
	Paper birch	200	2.4
	Total	1200	4.8
2	Balsam fir	600	1.2
	Red maple	400	1.5
	Total	1000	2.7
3	Sugar maple	1200	3.3
	Total	1200	3.3
4	Paper birch	1000	8.1
	Sugar maple	800	2.5
	Yellow birch	200	0.1
	Total	2000	10.7
5	Paper birch	200	1.0
	Bigtooth aspen	200	0.4
	Total	400	1.4
	Average	1160	4.6
	Standard deviation	572.7	3.6

Appendix 3. Continued.

Pence Upper Understory Stratum

Stand	Species	#/ha	sq m/ha
1	Balsam fir	1600	3.9
	Red maple	200	1.7
	Total	1800	5.6
2	Choke cherry	200	0.3
	Black spruce	200	1.8
	Total	400	2.1
3	Paper birch	600	3.8
	Balsam fir	200	1.6
	Total	800	5.4
4	White spruce	200	1.9
	Total	200	1.9
5	Black cherry	200	2.5
	Total	200	2.5
	Average	680	3.5
	Standard deviation	672.3	1.8

Appendix 3. Continued.

Vilas Upper Understory Stratum

Stand	Species	#/ha	sq m/ha
1	Balsam fir	200	0.1
	Total	200	0.1
2	Red maple	200	0.4
	Sugar maple	200	0.7
	Total	400	1.1
3	Balsam fir	400	1.3
	Paper birch	200	1.2
4	Black cherry	200	0.1
	Pin cherry	200	0.1
	Northern red oak	200	0.2
	Quaking aspen	400	3.2
	Jack pine	200	0.3
	Total	1200	3.9
5	Quaking aspen	400	1.5
	Jack pine	600	3.6
	Northern red oak	200	0.1
	Total	1200	5.2
	Average	720	2.6
	Standard deviation	460.4	2.1

Appendix 3. Continued.

Padus Lower Understory Stratum

Stand	Species	#/ha	% canopy coverage
1	Beaked hazel	3750	3.5
	Balsam fir	1250	1.0
	Total	5000	4.5
2	Beaked hazel	18750	37.5
	Total	18750	37.5
3	Sugar maple	2500	11.0
	Total	2500	11.0
4	Sugar maple	5000	32.5
	Total	5000	32.5
5	Beaked hazel	6250	37.5
	Total	6250	37.5
	Average	7500	24.6
	Standard deviation	6434.8	15.7

Appendix 3. Continued.

Pence Lower Understory Stratum

Stand	Species	#/ha	% canopy coverage
1	Beaked hazel	13750	30.0
	Balsam fir	2500	5.0
	Total	16250	35.0
2	Beaked hazel	3750	22.5
	Choke cherry	2500	15.0
	Total	6250	37.5
3	Round leafed dogwood	1250	1.0
	Total	1200	1.0
4	None		
5	Beaked hazel	8750	30.0
	Total	8750	30.0
	Average	6500	20.7
	Standard deviation	6519.2	18.6

Appendix 3. Continued.

Vilas Lower Understory Stratum

Stand	Species	#/ha	% canopy coverage
1	Beaked hazel	6250	3.5
	Total	6250	3.5
2	Beaked hazel	1250	1.0
	Total	1250	1.0
3	Balsam fir	7500	35.0
	Total	7500	35.0
4	Beaked hazel	63750	85.0
	Serviceberry	1250	2.0
	Northern red oak	1250	10.0
	Total	66250	97.0
5	Beaked hazel	10000	15.0
	Serviceberry	5000	16.0
	White pine	1250	3.5
	Choke cherry	1250	1.0
	Total	17500	35.5
	Average	19750	34.4
	Standard deviation	26654.6	38.7

Appendix 3. Continued.

Species Listed in Appendix 3

Balsam fir	*Abies balsamea* (L.) Mill.
Beaked hazel	*Corylus cornuta* Marsh.
Bigtooth aspen	*Populas grandidentata* Michx.
Black cherry	*Prunus serotina* Ehrh.
Black spruce	*Picea mariana* (Mill.) B.S.P.
Choke cherry	*Prunus virginiana* L.
Hophornbeam	*Ostrya virginiana* (Mill) K. Koch
Jack pine	*Pinus banksiana* Lamb.
Northern red oak	*Quercus rubra* L.
Paper birch	*Betula paperifera* Marsh.
Pin cherry	*Prunus pensylvanica* L.f.
Quaking aspen	*Populus tremuloides* Michx.
Red maple	*Acer rubrum* L.
Red pine	*Pinus resinosa* Ait.
Round leafed dogwood	*Cornus rugosa* Lam.
Serviceberry	*Amelanchier* spp.
Sugar maple	*Acer saccharum* Marsh.
White pine	*Pinus strobus* L.
White spruce	*Picea glauca* (Moench) Voss
Yellow birch	*Betula alleghaniensis* Britton

Appendix 4. Means and standard deviations for the graphical representation of factors influencing red pine seedling survival and growth on the Padus, Pence, and Vilas Ecological Land Types in northeastern Wisconsin.

Seedling Height (cm)

Date	ELT	Mean	S.D.
	Padus	14.8	3.1
7/3/86	Pence	16.3	3.7
	Vilas	15.4	3.3
	Padus	16.2	3.3
7/17/86	Pence	17.7	3.6
	Vilas	16.9	3.5
	Padus	17.5	3.4
7/30/86	Pence	19.2	3.8
	Vilas	17.9	3.6
	Padus	19.0	3.6
8/13/86	Pence	21.0	4.1
	Vilas	19.3	3.6

Seedling Diameter (mm)

Date	ELT	Mean	S.D.
	Padus	3.5	0.6
7/3/86	Pence	3.8	0.8
	Vilas	3.6	0.7
	Padus	3.7	0.7
7/17/86	Pence	4.0	0.8
	Vilas	3.8	0.7
	Padus	3.8	0.7
7/30/86	Pence	4.1	0.9
	Vilas	3.9	0.7
	Padus	4.0	0.7
8/13/86	Pence	4.3	0.9
	Vilas	4.0	0.7

Appendix 4. Continued.

Needle Water Tension (MPa)

Date	ELT	Mean	S.D.
	Padus	1.1	0.3
7/3/86	Pence	1.3	0.3
	Vilas	1.0	0.2
	Padus	0.9	0.2
7/17/86	Pence	1.0	0.1
	Vilas	1.3	0.2
	Padus	0.8	0.1
7/30/86	Pence	1.0	0.1
	Vilas	1.3	0.1
	Padus	1.0	0.1
8/13/86	Pence	1.0	0.1
	Vilas	1.2	0.1

Soil Water Tension (Centibars)

	Padus	7.5	2.6
7/3/86	Pence	11.3	4.0
	Vilas	12.8	4.1
	Padus	7.3	2.2
7/17/86	Pence	13.0	1.4
	Vilas	20.0	4.2
	Padus	7.5	1.7
7/30/86	Pence	10.5	1.0
	Vilas	25.3	11.3
	Padus	8.0	1.8
8/22/86	Pence	8.8	1.5
	Vilas	22.8	9.8

Appendix 4. Continued.

Total Soil Nitrogen (%)

Date	ELT	Mean	S.D.
	Padus	0.095	0.029
7/3/86	Pence	0.107	0.032
	Vilas	0.090	0.010
	Padus	0.096	0.017
7/17/86	Pence	0.092	0.007
	Vilas	0.073	0.016
	Padus	0.110	0.022
7/30/86	Pence	0.086	0.017
	Vilas	0.068	0.004
	Padus	0.112	0.017
8/13/86	Pence	0.124	0.024
	Vilas	0.079	0.007

Ammonium (ppm)

Date	ELT	Mean	S.D.
	Padus	7.75	1.39
7/3/86	Pence	11.92	3.07
	Vilas	8.04	2.58
	Padus	8.21	2.74
7/17/86	Pence	9.75	2.36
	Vilas	4.98	2.39
	Padus	20.00	10.81
7/30/86	Pence	21.38	10.50
	Vilas	9.02	4.15
	Padus	14.00	5.32
8/13/86	Pence	20.66	8.01
	Vilas	7.19	1.94

Appendix 4. Continued.

Nitrate (ppm)

Date	ELT	Mean	S.D.
	Padus	4.82	2.40
7/3/86	Pence	2.89	0.71
	Vilas	2.62	0.42
	Padus	3.22	0.67
7/17/86	Pence	3.44	0.56
	Vilas	2.58	1.47
	Padus	3.50	1.57
7/30/86	Pence	4.02	0.82
	Vilas	2.06	0.59
	Padus	3.92	0.58
8/13/86	Pence	3.50	0.98
	Vilas	3.06	1.85

Soil Temperature (Celsius)

	Padus	21.4	2.0
7/3/86	Pence	23.4	1.6
	Vilas	16.4	2.0
	Padus	15.4	0.5
7/17/86	Pence	19.3	2.4
	Vilas	14.6	0.3
	Padus	13.9	0.6
7/30/86	Pence	12.9	0.5
	Vilas	12.7	0.7
	Padus	15.3	0.3
8/13/86	Pence	14.9	0.6
	Vilas	14.3	0.3