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Vegetation of the Forest River Biology Area in Relation to Environmental Gradients and Some Patterns and Processes of Nutrient Cycling

Douglas A. Wikum

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VEGETATION OF THE FOREST RIVER BIOLOGY AREA IN RELATION TO ENVIRONMENTAL GRADIENTS AND SOME PATTERNS AND PROCESSES OF NUTRIENT CYCLING

by
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A Dissertation

Submitted to the Faculty

of the

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in partial fulfillment of the requirements

for the degree of

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1972

This dissertation submitted by Douglas A. Wikum in partial fulfillment of the requirements for the Degree of Doctor of Philosophy from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

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Degree Doctor of Philosophy

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Date July 17, 1972

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ABSTRACT

Vegetation-environment relationships were studied in 40 plots located on the slopes and the floodplain within the University of North Dakota Forest River Biology Area in northeastern North Dakota. Three of these plots, each dominated by a different major tree species, were selected for a detailed study (May to October, 1971) of nutrient input by litterfall, throughfall, and stemflow.

Coverage values for 109 species of vascular plants and basal area, frequency, density, and mensuration data were determined for seven tree species. A total of 10 species of mosses and 15 of lichens are reported for the 40 plots.

Dominant (based on importance value) overstory species are Quercus macrocarpa, Tilia americana, and Fraxinus pennsylvanica var. subintegerrima. Subordinate overstory species include Ulmus americana, Acer negundo, Populus tremuloides, and Betula papyrifera. Tree-ring analysis indicates the present forest is less than 100 years old.

Correlation analysis reveals that the basal area of trees and the number and coverage values of herbaceous species is higher on lower elevations and south exposures. Slope inclination, aspect, and elevation more strongly influence the distribution of the herbaceous element than they do trees and shrubs.

Principal component analysis and Swan-Dix-Wehrhahn ordination were used to group objectively the 40 stands into five abstract community types. Principal component analysis produced similar but more distinguishable groupings than the Swan-Dix-Wehrhahn method.

Environmental soil parameters measured for each horizon within the rooting zone include available water capacity; pH; specific conductivity; cation exchange capacity; percentage organic matter; water soluble calcium, magnesium, sodium, and potassium; replaceable calcium, magnesium, sodium, potassium, strontium, and manganese; available phosphorus; and EDTA-extractable copper, strontium, manganese, zinc, nickel, iron, lead, aluminum, and silicon.

Topographic and soil parameters were used for stepwise-elimination multiple regressions to develop predictive equations for the distribution of plant species. Based on results from multiple regression analysis, gradients for potential solar beam irradiation, available water capacity, elevation, linear aspect, slope, and replaceable potassium were established. Using coverage values, ecological modalities of selected species are demonstrated along the quantified gradients. Generally, trees show a bimodal, shrubs and herbs a unimodal distribution. The distribution of community types along these gradients are also shown. Relationships of stands in several bivariate combinations show patterns of community type distribution resembling those obtained by stand ordination. Whereas pronounced vegetation differences occur between slopes and floodplain, the vegetation pattern on the slopes is continuous and overlapping.

Interception of incident rainfall by the *Tilia americana* canopy (24.3%) was higher than by the *Fraxinus pennsylvanica* (12.3%) and *Quercus macrocarpa* (11.4%) canopies.

Input of calcium, magnesium, potassium, and phosphorus in net rainfall (throughfall plus stemflow) was greatest under the *Tilia* canopy, and the input of sodium and sulfate was greatest under the *Fraxinus* canopy.

Although seasonally variable, total litter production, ranging from 247 to 265 g/m^2 for the collecting period, was nearly the same in the three sites studied. Calcium levels were noticeably higher in woody litter, and magnesium, potassium, and phosphorus were higher in non-woody litter. The largest input of mineral elements occurred as follows: calcium, sodium, potassium, phosphorus, strontium, zinc, and copper in the site dominated by *Tilia*; manganese, iron, and aluminum in the *Quercus* site; and manganese in the *Fraxinus* site.

The combined total input by net rainfall and litterfall of calcium, potassium, magnesium, phosphorus, and sodium in kilograms per hectare in the three sites ranged from 39.8 to 68.4, 22.5 to 37.6, 8.8 to 9.9, 5.6 to 10.6, and 17.5 to 20.8, respectively.

It is suggested that functional aspects on productivity and cycling in ecosystems be preceeded by well documented vegetation-environment relationships.

INTRODUCTION

Although forests cover only a small percentage of the total land area in North Dakota, they are a valuable resource for timber production, prevention of soil erosion, recreational purposes, and their inherent aesthetic value. These forests are limited primarily to stream valleys and are referred to as gallery forests.

Only a few studies, especially those dealing with environmental relationships, have been conducted on these forests. Recent work on the gallery forests in North Dakota includes the studies of Burgess and his students (Johnson, 1971; Keammerer, 1972; Wanek, 1967) and Nelson (1964). It is hoped this study will contribute to the limited knowledge of forest ecosystems in North Dakota.

This study was undertaken to examine some of the structural and functional aspects of a gallery forest ecosystem. Special emphasis was placed on the ecosystem approach in relating biotic and abiotic factors on two levels: (1) the structure and distribution of vegetation in relation to environmental gradients and (2) the functional role of litter production and rainfall in nutrient cycling.

The distribution of vegetation studied on the levels of environmental factors, populations, and community characteristics is termed "gradient analysis" (Whittaker, 1967). Gradient analysis, a complex approach, is in its early stages of development. Pioneer work in this area was done by Whittaker (1956, 1960) and later extended by Bray and Curtis (1957), Loucks (1962), Waring and Major (1964), and Whittaker and Niering (1965). More recently, Wali and Krajina (1972) utilized the gradient analysis approach and Bormann et al. (1970), Grigal and Arneman (1970), Mowbray and Oosting (1968), Siccama, Bormann, and Likens (1970), and Walker and Wehrhahn (1971) conducted studies closely related to but not completely gradient analysis in nature.

A number of the early studies have been in areas where the gradients controlling the distribution of vegetation are obvious (Greig-Smith, 1964). In addition, a number of workers have used environmental data based on qualitative gradients generally established from a large number of field observations. Quantitative data supporting environmental gradients are lacking (Haase, 1970). To overcome some of these shortcomings, this study was conducted in a small geographic area where environmental gradients are not as sharply pronounced as in a larger area. An attempt was made to quantify as many environmental parameters as possible in an effort to determine some of the more subtle vegetation-environment relationships. This study thus represents an intensive rather than an extensive effort in relating vegetation to environmental gradients.

Whittaker (1967) outlines two basic approaches to gradient analysis. One, "direct gradient analysis" is based on relating vegetation to predetermined or accepted environmental gradients, the other, "indirect gradient analysis" requires arrangement of vegetation in accordance with species composition and the subsequent relating of vegetation to respective environmental parameters.

The present study incorporates the methodology of both direct and indirect gradient analysis. In accordance with the gradient analysis approach, the specific objectives of this study were to: (1) obtain data on the distribution of the plant species within the study sites, (2) investigate interstand relationships and group stands into community types, (3) quantify topographic and soil factors associated with vegetation, (4) correlate the vegetation and environmental factors at the level of species and community types, and (5) determine the relative importance of environmental factors studied in the distribution of species and community types.

Water and nutrients are two of the essentials required for the maintenance of a forest ecosystem. Water is primarily fed into an ecosystem by rainfall, and nutrients by rainfall, dustfall, litterfall, and weathering of underlying rocks. Loss of water and nutrients associated with leaching and erosion from an ecosystem may be significant (Likens et al., 1967). Thus, the input of both is important in maintaining a balance in the ecosystem.

Production of litter and its important role in replenishment of nutrients in an ecosystem has been emphasized by Bray and Gorham (1964), Ovington (1962), and Rodin and Bazilevich (1967). Studies relevant to nutrient input by litterfall have been conducted in tropical forest ecosystems by Greenland and Kowal (1960) and Nye (1961). More recently, similar studies have been conducted by Carlisle, Brown and White (1967), Cole, Gessel, and Dice (1967), Hughes (1971), Nihlgard (1972), Reiners and Reiners (1970), and others in temperate forests.

Whereas litterfall constitutes a form of nutrient input from within an ecosystem, such is generally not true for rainfall and dustfall. Rainfall coming into a forested ecosystem is intercepted by plants in varying degrees depending on the species (Clements, 1971; Carlisle, Brown and White, 1965; Helvey and Patric, 1965). Rainfall that is not intercepted reaches the forest floor through stemflow or throughfall. The total input of water and nutrients by throughfall has been shown to be considerably more than that by stemflow (Carlisle _et al_., 1967; McColl, 1970; Nihlgard, 1970).

Not only do canopies of different tree species intercept different amounts of rainwater, but they also alter its chemical composition as it passes through. These alterations have been suggested to result from foliar leaching (Attiwill, 1966; Rodin and Bazilevich, 1967; Tukey and Mecklenburg, 1964) and from foliar absorption (Franke, 1967; Tukey, Wittwer, and Bukovac, 1962). The literature on these subjects is reviewed in detail by Attiwill (1966) and Thomas (1969).

The annual sum of nutrients in litterfall, dustfall, stemflow, and throughfall is a measure of the rate of the nutrient cycling (Nye, 1961). The present study included an investigation of some of the patterns and processes influencing the rate of nutrient cycling within this forest ecosystem. The specific objectives were to: (1) evaluate the seasonal variation in the production and nutrient content of tree litter and annual production and input of nutrients by litter within three forest sites, each dominated by a different tree species, (2) determine possible differences in the amount of interception of rainfall and alteration of chemical composition of rainfall by three species of trees, (3) measure total input of nutrients by stemflow and throughfall under each of these tree species, and (4) determine combined total input of nutrients by stemflow, throughfall, and litterfall and assess the contribution of each.

GENERAL DESCRIPTION OF THE STUDY AREA

Location

The Forest River Biology Area, an ecological field station of the University of North Dakota, is situated on the western edge of the Red River Valley in Grand Forks County, 80 kilometers northwest of Grand Forks, North Dakota, at 48°10'N latitude and 97°41'W longitude (Figure 1). The Forest River, which flows through the area, is one of three perennial streams in Grand Forks County which flow east and northeast into the Red River of the North. Similar streams in eastern North Dakota drain into the Red River at various intervals along the entire length of the valley. All of the valleys formed by these streams are for the most part forested in an otherwise prairie region.

The Biology Area (Figures 1 and 2) consists of 64.8 hectares (160 acres) including upland prairie and gallery forest located in S 1/2, SW 1/4, sec 11 and N 1/2, NW 1/4, sec 14, T154N, R55W. The upland prairie portions are located near the northwestern and southern boundaries at an elevation of 334 meters (m). Valley slopes range from 5 to 40° and converge on the floodplain at an elevation of about 312 m.

Small perennial and intermittent spring-fed streams have eroded several large coulees which lead into the river. The largest perennial spring is the "Inkster Spring" which enters the Biology Area from the

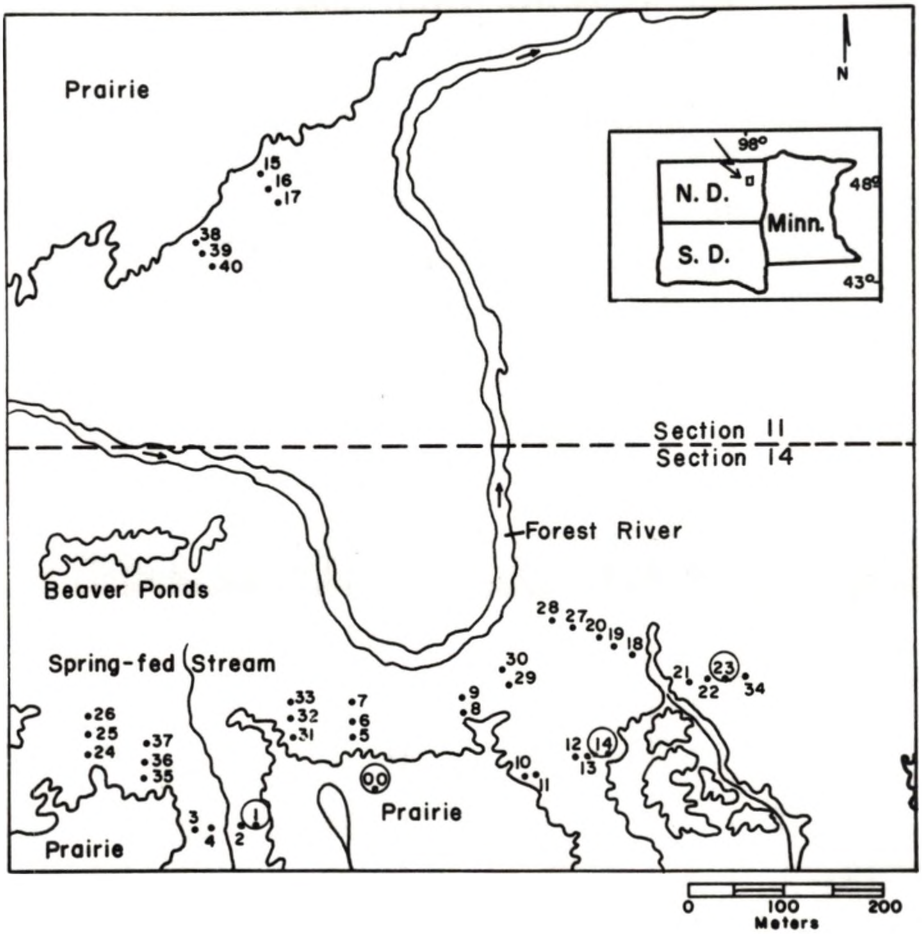

Prairie
N
98°
N. D.
Minn.
48°
S. D.
43°
15
16
17
38
39
40
Section 11
Section 14
Forest River
Beaver Ponds
Spring-fed Stream
28
27
20
19
18
30
29
21
22
23
34
26
25
24
37
36
35
33
32
31
7
6
5
9
8
12
14
13
10
11
00
1
2
3
4
Prairie
Prairie
0
100
200
Meters

Fig. 2.--An aerial view of the central portion of the Forest River Biology Area.

southwest. It has a seasonal range in discharge of 200 to 700 gallons per minute (Kelly and Paulson, 1970). These coulees and the river valley itself provide slopes of different exposure and slope inclination. Resulting diversity in environment has produced a rich vegetation within a small geographic area. Because of this, the area was considered ideal for a gradient-analysis study.

Climate

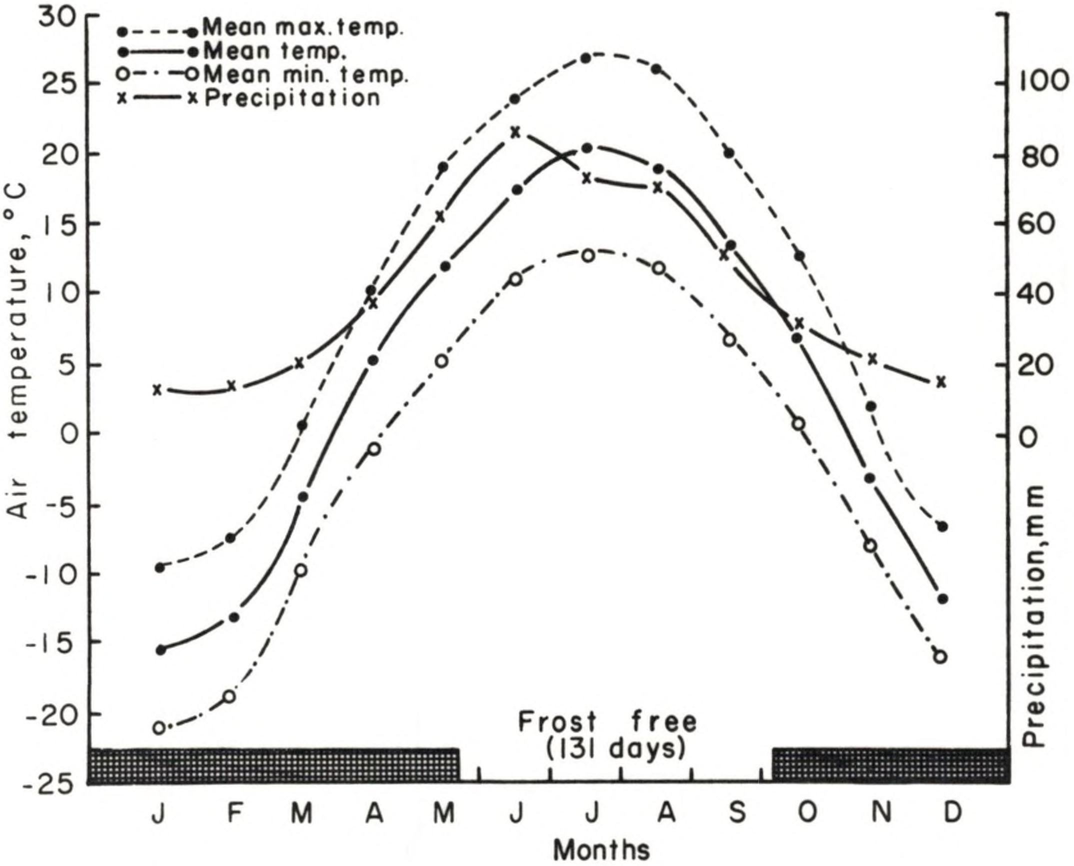
The climate of Grand Forks County is subhumid and mesothermal (Thornthwaite, 1948) and is characterized by a wide temperature range, cold dry winters, and short, warm, moist summers. The prevailing winds are northwesterly and monthly averages range from 12.8 to 17.6 kilometers per hour (U.S. Department of Commerce, 1959).

A climatic diagram for Grand Forks, North Dakota, based on 69 year records (1898 to 1966), is shown in Figure 3. This data (U.S. Department of Commerce, 1967) is representative of weather conditions in the study area. The mean annual temperature is 4.05° C (39.3° F), the mean daily minimum is -2.06° C (28.3° F), and the mean daily maximum is 10.1° C (50.20° F). January is the coldest month, with a mean monthly temperature of -15.4° C (4.2° F), and July is the warmest month, with a mean monthly temperature of 20.6° C (69.2° F). Day length ranges from 9 1/4 hours on January 21 to 16 1/4 hours on June 21.

The average dates for the last killing frost in the spring and the first killing frost in the fall are May 15 and September 24. The average frost-free season is 131 days. This is a relatively short growing season.

Fig. 3.--Climatic diagram for Grand Forks, North Dakota based on 69 year records (1898 to 1966).

Grand Forks, N.D.
Elevation: 830'
Latitude: 47° 56'N
Longitude: 97° 05'W



Average depth of frost penetration varies from 1.1 to 1.4 m (McClelland et al., 1959). Mean annual total precipitation is 508 millimeters (mm). This amount includes an average of 889 mm of snow (U.S. Department of Commerce, 1967). More than three-fourths of the precipitation is received from April to September.

Geology

The geology of Grand Forks County is described in detail by Hansen and Kume (1970) and is the basis for the following discussion. All of eastern North Dakota was at one time glaciated with the most recent glaciation being late Wisconsin. During this period, ice blockage of existing river systems resulted in the formation of Lake Agassiz. A portion of this lake occupied what is presently known as the Red River Valley.

The study area lies on the western edge of the Red River Valley. Topographically, the district slopes slightly eastward toward the Red River. The geology here is complex because the area has been both glaciated and covered by an ancient lake. As a result, both glacial and lacustrine deposits are present. The glacial deposits are late Wisconsin and consist of a series of till sheets with a combined thickness of approximately 60 m. The most recent sheets have been radiocarbon dated at 13,000 years (Clayton, 1972). Overlying these is a 15 m layer of stream sediment composed of sand and gravel. This was formed when the margin of the glacier persisted for some time a short distance east of the research area. Superimposed upon these deposits is a beach with a total thickness of 1.5 to 3.0 m. It marks a former level of glacial Lake Agassiz.

Bedrock lies 75 to 90 m beneath the surface and consists of Paleozoic and Mesozoic sedimentary rocks overlying Precambrian metamorphic and igneous rocks.

The Forest River, which has its headwaters in the drift prairie to the west, has cut deeply through beach and outwash deposits exposing glacial-till on lower valley slopes. In places on the valley floor, the scouring action of the river has exposed patches of boulder pavement.

Stream deposits on the floodplain are sandy, reflecting their origin from local beach and outwash materials. They are much coarser than the silt and clay found farther east where the river flows over lake sediments deposited on the bottom of glacial Lake Agassiz.

Permeable deposits are an important source of water storage in subhumid regions. One of these deposits, the Inkster Aquifer, underlies the southern part of the Biology Area. The water table slopes northward towards the boundary of the aquifer, the Forest River, providing a source for the springs present on the north-facing slopes (Kelly and Paulson, 1970). Some discharge areas exist on lower north-facing slopes and following periods of heavy rainfall may account for slumping on these slopes. The presence of this aquifer affects the moisture regime on lower north-facing slopes.

Soils

The soils of eastern North Dakota are predominantly Haploborolls (Chernozems) which have formed under tall grass vegetation on glacial, stream, or lake parent material (Omodt et al., 1968). They have very dark A horizons that are high in organic matter and have low carbon to nitrogen ratios (McClelland et al., 1959). Soils in most of the study area are Haploborolls, but Ustifluvents are present on the floodplain. Soils on the upper slopes have developed on beach sand and outwash parent material, those on lower slopes on glacial-till, and those on the floodplain on sandy stream sediments. Thick eolian deposits occur on south and southeast-facing slopes.

Slope inclination and shape are two important topographic features that influence the soil-forming processes. The slopes studied within the Biology Area range from 6 to 32°. Most are convex and have steeper slopes at lower elevations. Generally, convex slopes are subject to runoff; however, in the study area this is offset by coarse-textured soils, particularly at higher elevations. As a result, except during very heavy rains, infiltration is rapid, and there is very little runoff.

Vegetation

According to Kuchler (1964) the potential natural vegetation of the Red River Valley is Bluestem Prairie (Andropogon-Panicum-Sorghastrum) together with Northern Floodplain Forest (Populus-Salix-Ulmus). He defines potential natural vegetation as that which would be present today if unaltered by man. Under the influence of man, the actual vegetation present today is considerably different than the potential. Fertile soils and adequate rainfall resulted in the plowing of the original prairie for agricultural use. As a result, although Bluestem Prairie does exist, it occupies only a small fraction of the total land area. The floodplain forests today may more closely approach the potential natural vegetation than does the prairie. Although disturbed by man as a result of grazing and lumbering, they still contain populations of Populus, Salix, and Ulmus. In addition to Kuchler's potential species, Fraxinus pennsylvanica var. subintegerrima (green ash), Betula papyrifera (paper birch), Tilia americana (American basswood), Acer negundo (box elder), and Quercus macrocarpa (bur oak) are present in the Forest River Valley. Basswood is the only dominant tree of the maple-basswood association of the eastern deciduous forest that extends this far west.

Rudd (1951) grouped the then reported 900 species of native plants in North Dakota into groups of 55% intraneous and 45% extraneous species. Of the extraneous species, she concluded 20% were of eastern deciduous forest origin and 15% from northern coniferous forest. Present day forest vegetation of the Forest River Valley had its postglacial origin from these two sources. Similarity in species composition in bur oak groves in east central Minnesota (Buell and Facey, 1960) and in the Forest River Valley supports this premise that many species here are of the eastern deciduous forest origin. All 10 species of the conspicuous shrubs and 14 of the 15 conspicuous herbs reported by Buell and Facey (1960) in the oak groves are present in the Forest River Biology Area. Seven of the 10 shrub species are abundant and include, Corylus americana, C. cornuta, Prunus virginiana, Rubus idaeus, Symphoricarpos occidentalis, Viburnum lentago, Celastrus scandens, and Rhus radicans. Herbaceous plants common to both areas include Aralia nudicaulis, Anemone canadense, Agastache foeniculum, Maianthemum canadense, Smilacina racemosa, S. stellata, and Thalictrum dasycarpum.

Species of the northern coniferous forest representing a southern extension of the Saskatchewan mixed forest (Whitman, 1954), include Populus tremuloides (trembling aspen), Betula papyrifera, Amelanchier alnifolia, Cornus stolonifera, Viola rugulosa, and Pyrola secunda. A significant feature of the vegetation in the Forest River Valley is the complete lack of coniferous species; yet a conifer, Juniperus communis, is abundant on the slopes of the Park River Valley only 35 miles to the north.

The gallery forest present here today can best be described as a western extension of the eastern deciduous forest combined with the elements of northern coniferous forest. It consists of species that have extended their range into this region by means of the unique environmental conditions present in the river valleys.

Historical and Biotic Factors

George T. Inkster, for whom the Inkster township was named, was the first settler in 1876. By 1879 and 1880 every available timber claim was occupied (Arnold, 1916). The wooded areas were more in demand as opposed to the open prairie because of their nearness to water and because they provided a supply of fuel and building materials. Sawn lumber, either native or imported from Minnesota, remained a scarce commodity (Arnold, 1916).

The Forest River Biology Area was described in the Original Land Survey (1880)"as gently undulating, first rate, with timber of oak, elm, and basswood." The elm mentioned was most likely Ulmus americana, (American elm),the only species found here today. No mention was made of the presence of green ash in sections 11 and 14 in the 1880 document.

Annual fall prairie fires often entered the valleys (Arnold, 1916). Today, charcoal found occasionally just under the soil surface provides evidence of this fact. Numerous fragments of bison bones are found in the area attesting to the fact that bison were once abundant in this river valley and the surrounding prairie.

During flood stage, blockage of the river by downed trees and by beaver dams may have aided in the shifting of course of the river (Arnold, 1916). The general effect of repeated shifting was responsible for widening of the valley floor and formation of the present floodplain. Beaver, abundant here prior to settlement, were apparently eliminated by the late 1800's. They were reintroduced into the area in the 1930's by the State Game and Fish Department (Norman, 1966). Since that time, they have played an important ecological role by damming of the river and the spring-fed streams leading into the river. By frequently cutting woody plants for dam building and food sources, they have played a major role in preventing the forest from maturing in several areas adjacent to the river. Old beaver-cut stumps and gnaw marks on trees found at elevations of about 330 m indicate that in the past the beaver have ranged to the top of the wooded slopes.

GRADIENT ANALYSIS PROCEDURES

Field Methods

Vegetation

One of the principal objectives of this study was to determine the distribution pattern of the vegetation on the wooded slopes and compare such patterns with those on the floodplain. The vegetation was sampled selectively by means of 40, 10 x 10 m plots. The initial 26 plots on wooded slopes were studied during June through August, 1970. In June and July, 1971, an additional 14, 10 x 10 m plots were studied; 10 were on the wooded slopes and four were on the floodplain.

The plots were laid down the slope along a transect at 10 m intervals. The uppermost plots were selected to assure the representation of a maximum number of vegetation types. This resulted in a series of two to four plots along each transect, depending upon the length of the forested area of the slope. The floodplain sites were selected to be typical of the vegetation there.

Each 10 x 10 m plot was subdivided into four 2.5 x 2.5 m subplots to facilitate cover-abundance estimates of herb and shrub layers. Topographic characteristics determined in each plot included slope angle, aspect, and elevation at the upper edge of the plot. Plants were assigned to strata and cover-abundance values were determined for all species according to a slightly modified Braun-Blanquet (1932-1964) scale as follows:

Class	Coverage
+	0- 5%
1	5- 10%
2	10- 25%
3	25- 50%
4	50- 75%
5	75-100%

Trees, 3 m or taller, were assigned to the A stratum. Each of the trees in this stratum had a diameter greater than 25 centimeters (cm). Shrub and tree species between 2 and 3 m were assigned to the B_1 stratum and those shorter were assigned to the B_2 stratum. The herbaceous species were assigned to the C stratum. Coverage values for each species in each stratum and substratum were determined in each of the four 2.5 x 2.5 m subplots of each plot, then summed and averaged.

Tree heights were measured by a Spiegel Relaskop. Diameter at breast height values measured were later converted to basal area in square centimeters. Tree-core samples were obtained to determine the tree ages. Generally, cores were taken from trees representing the largest, smallest, and intermediate size of the A stratum. Importance values for all tree species in the A stratum were determined as the sum of the relative frequency, relative density, and relative dominance (Curtis, 1959).

Representative samples of species of mosses and lichens were collected from each plot. Most of these occur on dead wood or tree trunks, which made coverage value determination very difficult. Therefore, mosses and lichens are reported on a presence-absence basis.

Nomenclature for vascular plants follows Fernald (1950) and Stevens (1963), for mosses Crum, Steere, and Anderson (1965), and lichens Hale and Culberson (1965). Voucher specimens of vascular plants, mosses, and lichens are on file in the University of North Dakota herbarium.

Soil

A soil pit was excavated close to the center of each of the 40 plots. Soil profiles were described according to the U.S. Department of Agriculture Soil Survey Manual (1951). The descriptions included the thickness, color, structure, consistence of each horizon, the root distribution in each profile, and the depth of the maximum rooting zone. Each profile was photographed in its natural state and as a miniature. The miniature or "mini" monolith (Figure 4) was made by placing small amounts of soil from each horizon on a 12 x 20 cm sheet of white cardboard (Wali and Krajina, 1972).

Metal cylinders, 5 cm tall and 5 cm in diameter, were used to collect soil cores from each mineral soil horizon. These samples, used to determine bulk density and field water, were sealed in plastic bags to prevent water loss. Additional soil samples for nutrient and trace metal analyses and water retention characteristics were collected separately from the humus layer and each mineral horizon within the rooting zone. This was done by scraping mineral soil from the entire width of each horizon. The inclusion of the humus layer, however thin, assured in obtaining a more realistic picture of the capacity of the soil to supply water and nutrients to the roots.

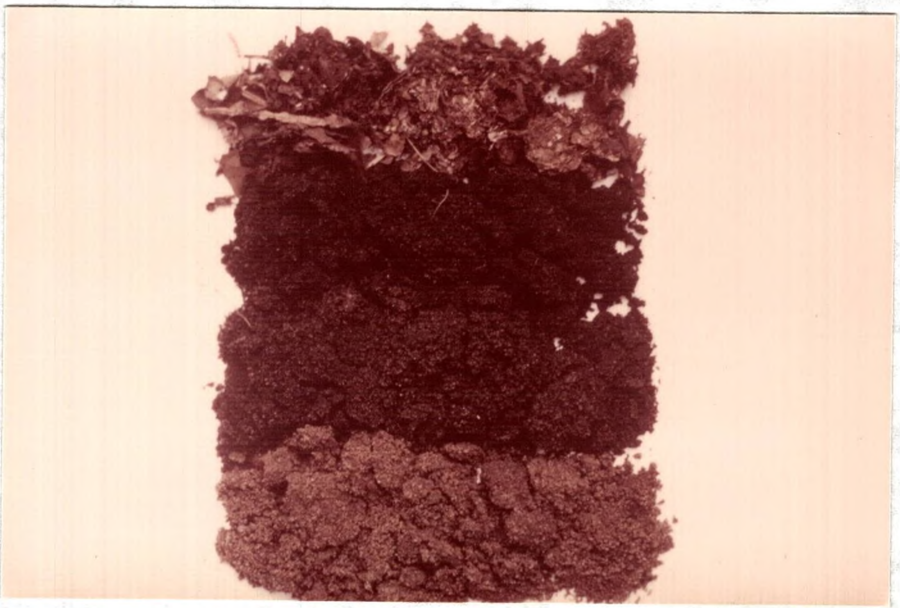


Fig. 4.--"Mini" monolith of a Pachic Haploboroll under Quercus macrocarpa (plot 15).

Seasonal changes in the amount of available water in the soil of stands 1, 14, and 23 were measured with gypsum moisture blocks and Bouyoucos Model BN-2B moisture meter. Two blocks were installed in each soil pit, one at a depth of 20 cm and the other at the maximum rooting depth. Available water levels below 20% cannot be read on the moisture meter. These are taken to approximate the permanent wilting percentage.

Laboratory Methods

Bulk density and field water were determined for all mineral soils. The bulk density of the humus layer, too thin to obtain a core sample, was estimated. Bulk density values are expressed as grams per cubic centimeter.

Water retention values at 1/3 bar and 15 bars soil water tension were measured by pressure plate and ceramic plate apparatus (Richards, 1954). In addition, water retention values at 1, 5, and 10 bars were determined for soils from plots 1, 14, and 23. The available water capacity (AWC) was calculated as the difference between the 1/3 bar and 15 bar levels. This value, corrected for bulk density and stoniness, was used to calculate the available water capacity for each horizon within the rooting depth (AWC)rd. These values were summed for all horizons in each profile and are expressed as centimeters of water per centimeter of soil depth (Wali and Krajina, 1972; Waring and Major, 1964).

Particle-size distribution in soils was determined by the hydrometer method (Bouyoucos, 1951). Hydrogen peroxide was used to oxidize organic matter. The soil samples were agitated on a reciprocal shaker for 24 hours prior to analysis. The amount of silt plus clay for each horizon was later used to calculate a weighted average of percentage silt plus clay (%si+cl) for all horizons within the rooting depth (rd).

The major cations, calcium, magnesium, potassium, and sodium, were measured for both replaceable and water soluble fractions and strontium and manganese on the replaceable fraction. In keeping with usage by Wali and Krajina (1972), the replaceable cations represent both water soluble plus exchangeable components. The water soluble fraction was extracted in a 1:2.5, soil:water ratio. The replaceable fraction was extracted with 1 normal ammonium acetate at pH7±0.2. A 1:10, soil:ammonium acetate ratio was used. After extraction, both the soluble and replaceable fractions were filtered. The trace metals, copper, strontium, manganese, zinc, nickel, iron, lead, aluminum, and silicon, were measured after extraction with 0.02 molar disodium-ethylenediaminetetraacetate (EDTA) at pH 6.8. A 1:5, soil:EDTA ratio was used for this extraction.

Levels of major cations and trace metals were determined on a Perkin-Elmer Model 403 Atomic Absorption Spectrophotometer. Available phosphorus was determined on 2 gram (g) soil samples by the chlorostannous-molybdophosphoric blue color method (Jackson, 1958). Replaceable nutrients are expressed as millequivalents (meq)/100 g, water soluble nutrients as meq/liter, and available phosphorus and trace elements in parts per million (ppm). The replaceable and soluble fractions are expressed in millequivalents because these ions are taken up by the plants on the basis of their stoichiometric properties and not by weight (Waring and Major, 1964).

Levels of water soluble nutrients, replaceable nutrients, trace elements, and available phosphorus were used to calculate available nutrients for each horizon within the rooting depth. These values, corrected for bulk density, were summed for each profile. Replaceable nutrients are expressed as equivalents (eq)/m^2 and water soluble, trace elements, and available phosphorus as g/m^2. A square meter basis was used because bulk density, stoniness, and horizon thickness are taken into account in assessing nutrient availability (Waring and Major, 1964).

Electrical conductivity (micromhos/cm) and pH were determined from the same 1:2.5, soil:water samples used to measure the water solubel nutrient levels. In addition, pH was also determined on a 1:2, soil: 0.01 molar $CaCl_2$ solution (Schofield and Taylor, 1955). Electrical conductivity was determined on a Radiometer type CDM2e conductivity meter and pH on a Radiometer model 51 pH meter.

The Walkley-Black method (Jackson, 1958) was used to measure the amount of organic matter. Weighted averages of percentage organic matter (%OM) were calculated for each soil horizon by the same procedure as for percentage silt plus clay.

The cation exchange capacity of soils was determined by saturation with 1 normal sodium acetate followed by replacement of the sodium on the exchange complex with 1 normal ammonium acetate at pH7±0.2 (Jackson, 1958). Filtered samples were analyzed for sodium levels by atomic absorption spectrophotometry. The measurements of cation-exchange capacity are expressed as meq/100 g of soil.

Synthesis of Data

Vegetation

The Braun-Blanquet type association synthesis of the data from this area was not possible. Two reasons may be cited for this apparent impossibility: (1) the woodland, previously disturbed, is very young and probably represents one of the early stages of succession and (2) abrupt boundaries in the habitat within the wooded area (except between the floodplain and slope) are not present, the whole vegetation spectrum resembling more a continuum pattern of vegetation. Therefore, in order to analyze interstand relationships, two ordination procedures, principal component analysis and the Swan-Dix-Wehrhahn technique, were employed. The objective of both of these methods, as used in this study, is the placement of stands relative to one another (Greig-Smith, 1964).

The ordination technique developed by Swan, Dix, and Wehrhahn (1969) differs from the methods of Bray and Curtis (1957) and Beals (1960) in its use of the euclidean index. Additionally, the axes are selected from those that account for the highest proportion of the sum of squares for interstand distances as opposed to the distant stand criterion of the Bray and Curtis method. The computer program SDWORD used for the Swan-Dix-Wehrhahn ordination was written at the North Dakota State University Computer Center.

The principal component analysis program used (FACTO 1) was supplied by IBM. The method employed is a principal component solution with varimax rotation of the factor matrix. A Q-type matrix (Orloci, 1966) was used to obtain stand loadings. Barkham and Norris (1970) in their evaluation of principal component analysis preferred it to other types of factor analysis because it requires a minimum of assumptions and is computationally unambiguous.

The ordinations and all other computations for this study were done on an IBM 360/40 digital computer at the University of North Dakota. In order to stay within the working core space of the computer, the coverage values for only 75 species were used for the ordinations. All woody species and herbaceous species occurring in 10% or more of the stands were included in the 75 x 40 matrix. Woody plants of the same species occurring in the B_1 and B_2 strata were treated as separate species.

Results from these mathematically different ordination procedures provide an opportunity for comparison of their effectiveness on fairly complex data. According to Jeglum, Wehrhahn, and Swan (1971) few studies have been made which allow for judging the effectiveness of principal component analysis with data of varying complexity. Swan et al. (1969) indicated that no comparisons of their method with other techniques had been made. This effort, therefore, may represent the first attempt to compare these methods.

Vegetation-environment Relationships

Stepwise-elimination multiple regressions were used to develop predictive equations ("models") for plant response to environmental parameters. A set of environmental parameters (independent variables) were used to predict a presence-absence value (dependent variable) for each species. The computer program (STWMULT) used is an IBM scientific subroutine package.

A total of 14 environmental parameters were selected from among 25 measured for the regressions. The variables selected include those which have been shown to be important ecologically in the distribution of plant species. These initial independent variables included: (1) replaceable calcium, magnesium, and potassium; (2) available phosphorus, manganese, zinc, and iron; (3) available water capacity within the rooting depth (AWC)rd; (4) weighted average of percentage silt plus clay within the rooting depth (%si+cl)rd; (5) weighted average of percentage organic matter within the rooting depth (%OM)rd; (6) topographic features elevation, slope inclination, and linear aspect; and (7) potential solar beam irradiation (PSBI). Potential solar beam irradiation values, expressed in 10^3 x langleys per year, were obtained by interpolation from tables prepared by Frank and Lee (1966). These values provide an indirect, integrated measure of slope inclination and aspect.

Data on circular aspect cannot be interpreted in a meaningful way when analyzed statistically by correlation and regression procedures. To circumvent this problem, aspect was expressed in a linear form from 1°

(North) to 180° (South). Aspects from 180° to 360° were assigned the same value as those from 1° to 180°, which have the same amount of potential solar beam irradiation. For example, west-facing slopes, which receive the same amount of potential solar beam irradiation as east-facing ones with the same slope inclinations, were assigned a value of 90°.

The initial series of multiple regressions involved 50 of the species used for the ordinations. These 50 species included all the species in the A stratum plus those in the B_1, B_2 and C strata with the highest presence values. A second series was run using logarithmic (base 10) transformations of all independent variables except the topographic features. The assumption that these would give more meaningful regression equations is based on the fact that plants respond more logarithmically than linearly to environmental factors such as soil water and nutrients (Leyton, 1958; Loucks, 1962; and Partch, 1949).

The stepwise-elimination regression used excludes the independent variable with the lowest T-values for each subsequent regression. Only those remaining independent variables that had statistically significant T-values at the 0.05 level were used to calculate the regressions. Synthetic gradients were established on the same statistically significant variables retained most often in the regression equation. Maximum value of each established gradient was adjusted at 100; consequently, all values are comparable. Relative coverage values for each major species were plotted along these gradients, establishing ecological modalities for each (Wali and Krajina, 1972; Waring and Major, 1964).

These gradients were also used in bivariate combinations to show relationships between stands. Each combination consists of two related environmental factors with isolines encircling stands included in each community type, forming the third dimension.

RESULTS OF GRADIENT ANALYSIS

Vegetation

Within the 40 stands, a total of 109 species in 37 families of vascular plants were recorded. This constitutes 26% of about 425 species previously reported in the Biology Area (Facey, 1972). In addition to the vascular plants, a total of 10 species of mosses and 15 species of lichens were collected within the 40 stands. Only one fern species, Botrychium virginianum, was present in the plots studied. However, Pteretis pennsylvanica is fairly abundant in the ravine between plots 11 and 12 and seems to be increasing in numbers on the floodplain. A listing of the vascular plants and their respective coverage classes for each stand is shown in Table 1. This table also includes a list of lichens and mosses reported for each stand by presence. Species of plants occurring in only one plot are referred to as "sporadic" species and are listed separately at the bottom of the table. A complete species list for vascular plants, mosses, and lichens is found in Appendix A.

Results from the study of the A stratum are presented in Table 2. This data shows bur oak has the highest importance value. Basswood followed by green ash has the next highest importance value. Importance values of the four remaining overstory species are considerably less than the first three. Based on importance values, bur oak, basswood,

TABLE 1

PHYTOSOCIOLOGICAL TABLE SHOWING COVER-ABUNDANCE VALUES OF VASCULAR PLANTS AND OCCURRENCE OF MOSSES AND LICHENS IN THE 40 PLOTS STUDIED

TABLE 2

SUMMARY OF VEGETATION ANALYSIS OF THE A STRATUM IN 40 PLOTS

Species	Frequency Percentage	Relative Frequency Percentage	Density (stems per hectare)	Relative Density Percentage	Basal area (m^2 per hectare)	Relative Dominance Percentage	Importance Value
Quercus macrocarpa	62.5	29.4	305	38.0	100.8	40.4	107.8
Tilia americana	50.0	23.5	177	22.1	61.8	24.8	70.4
Fraxinus pennsylvanica	52.5	24.7	175	21.8	36.6	14.7	61.2
Acer negundo	15.0	7.1	42	5.3	25.4	10.2	22.6
Betula papyrifera	12.5	5.9	45	5.6	10.9	4.4	15.9
Ulmus americana	12.5	5.9	32	4.0	7.4	3.0	12.9
Populus tremuloides	7.5	3.5	25	3.1	6.4	2.6	9.2
Total		100.0	801	99.9	249.3	100.1	300.0

and green ash are judged to play the role of dominant species. Box elder, paper birch, American elm, and trembling aspen are subordinates. The mensuration data collected from the 40 stands (Table 3) provides an insight into age and size distribution for the seven tree species. Bur oak has the widest range of age, height, and basal area, and the highest mean values of age and basal area. Aspen represents the other extreme for age and basal area. Based on mean height, box elders are the tallest trees in the area. These are primarily restricted to the floodplain where, typically, canopies are uniformly high. However, these trees belong to lower age classes which probably reflects the rapid rate of growth for the species. The data for paper birch and aspen reveals a general absence of younger and shorter trees. Maximum age of all trees, with the exception of one 150-year old bur oak, indicates that these have been established since the original settlement in the 1880's.

Topography and Vegetation

The major topographic features, elevation, aspect, and slope inclination, are known to play a significant role in determining structural characteristics of vegetation (Whittaker, 1956, 1960; Whittaker and Niering, 1965). Correlations between these topographic features and stand vegetation characteristics are shown in Table 4. The four floodplain stands were not included in the correlation analysis because data from these nearly level sites would have obscured the topographic-vegetation relationships on the slopes. The ranges, means, and standard

TABLE 3

MENSURATION DATA OF THE TREES IN 40 STANDS

	Tree ages in years				Tree height in meters				Basal area in cm^2			
Species	range	mean	SD[a]		range	mean	SD[a]		range	mean	SD[a]	
Quercus macrocarpa	37-150	69.8	±19.05	(43)[b]	3 -19	8.3	±3.16	(122)	67-1605	322.1	±281.29	(122)
Tilia americana	16- 75	43.6	±19.25	(30)	3 1/2-17 1/2	8.6	±2.88	(73)	62-1911	392.5	±359.50	(73)
Fraxinus pennsylvanica	28- 89	50.5	±18.85	(28)	3 1/2-16 1/2	8.4	±2.80	(70)	52- 666	210.6	±159.17	(70)
Acer negundo	19- 49	35.2	± 9.86	(8)	5 -16	10.6	±3.53	(17)	74-1253	598.3	±405.74	(17)
Betula papyrifera	19- 41	30.2	± 7.01	(8)	7 -11 1/2	9.2	±1.32	(18)	114- 630	243.1	±115.35	(18)
Ulmus americana	33- 79	53.5	±14.72	(7)	3 -15	10.0	±3.86	(13)	62-1136	296.8	±360.73	(13)
Populus tremuloides	16- 33	23.2	± 6.87	(6)	5 1/2-12 1/2	9.0	±2.24	(10)	94- 401	264.7	± 97.99	(10)

[a] standard deviation

[b] numerals in parentheses indicate number of trees measured

TABLE 4

RANGES, MEANS, AND STANDARD DEVIATIONS FOR STAND CHARACTERISTICS OF VEGETATION IN THE 36 STANDS OCCURRING ON SLOPES AND PRODUCT-MOMENT CORRELATIONS BETWEEN THESE VALUES AND ELEVATION, SLOPE, AND LINEAR ASPECT

Stand Characteristics	Range	Mean±SD	Correlation coefficients Elevation	 Slope	 Linear aspect
Basal area (cm^2)	460-5538	2440±1140.7	-0.495[a]	0.046	0.478[a]
Tree density (stems/stand)	2- 23	8± 4.4	-0.248	0.166	0.353[b]
Tree coverage (percentage)	20- 90	64± 19.7	-0.079	-0.084	0.015
B$_1$ coverage (percentage)	5- 75	36± 20.9	0.337[b]	-0.017	-0.376[b]
B$_2$ coverage (percentage)	10- 50	26± 12.1	-0.199	-0.083	0.095
C coverage (percentage)	20- 95	78± 19.1	-0.358[b]	-0.042	0.403[b]
Tree species (no./stand)	1- 4	2± 0.7	-0.248	0.166	0.353[b]
Shrub species (no./stand)	8- 17	12± 2.3	0.089	0.025	-0.251
Herb species (no./stand)	7- 27	14± 5.1	-0.398[b]	0.393[b]	0.187
Total species (no./stand)	18- 41	29± 6.1	-0.311	0.369[b]	0.054

[a] significant at 0.01 level

[b] significant at 0.05 level

deviations for the topographic features are as follows: (1) elevation, ranges from 313 to 334 m with a mean of 325±6 m, (2) slope angles, range from 6 to 32° and a mean of $16\pm7^{\circ}$, and (3) linear aspect, ranges from 1 to 157° with a mean of $61\pm51^{\circ}$.

Table 4 shows that there are statistically significant correlations between elevation and linear aspect and several characteristics of vegetation. However, the only statistically significant correlations with slope angle exist for both the number and cover-abundance of herbaceous species. A significant negative correlation exists between basal area of a plot and elevation while a significant positive correlation occurs between elevation and linear aspect.

There is also a significant positive correlation between tree density and linear aspect. If tree density and basal area are considered as measures of productivity, then productivity in the A stratum is higher on lower south-facing slopes.

Coverage values of B_1 in relation to topography show an opposite trend than that for trees. Shrubs in the B_1 show a positive correlation with elevation and a negative correlation with linear aspect. The general pattern emerging for shrubs shows that their coverage value increases in the B_1 on higher elevations and toward north-facing slopes. The number of shrub species shows no statistical correlation with any of the three topographic features, which suggests that they are somewhat uniformly distributed on the slopes.

Negative correlation between coverage values of the C stratum and elevation and linear aspect indicates that, unlike the shrubs in the B_1, the coverage of this stratum increases at lower elevations and toward south-facing slopes. Similarly, a significant negative correlation exists between the number of herbaceous species and elevation. The significant positive correlation between number of herbaceous species and slope angle is coincidental with the fact that the steeper slopes are generally located at lower elevations. Thus, herbaceous species seem to be more strongly influenced by slope than the shrubs. In general, there are more herbaceous species on lower, steeper slopes and herbaceous species have higher coverage values on lower, more south-facing slopes.

Ordination and Community Types

Principal component analysis and the Swan-Dix-Wehrhahn ordination were used to objectively group the 40 stands into five abstract community types. These groupings are shown in Figures 5 and 6. Both of these methods produced remarkably similar results, which are nearly mirror images of each other. Plots of the loadings from varimax rotation of the axes obtained from principal component analysis failed to produce any meaningful groupings.

A comparison of the effectiveness of the two ordination procedures used is shown in Table 5.

Fig. 5.--Position of 40 stands based on principal component analysis. Note the clustering of community types.

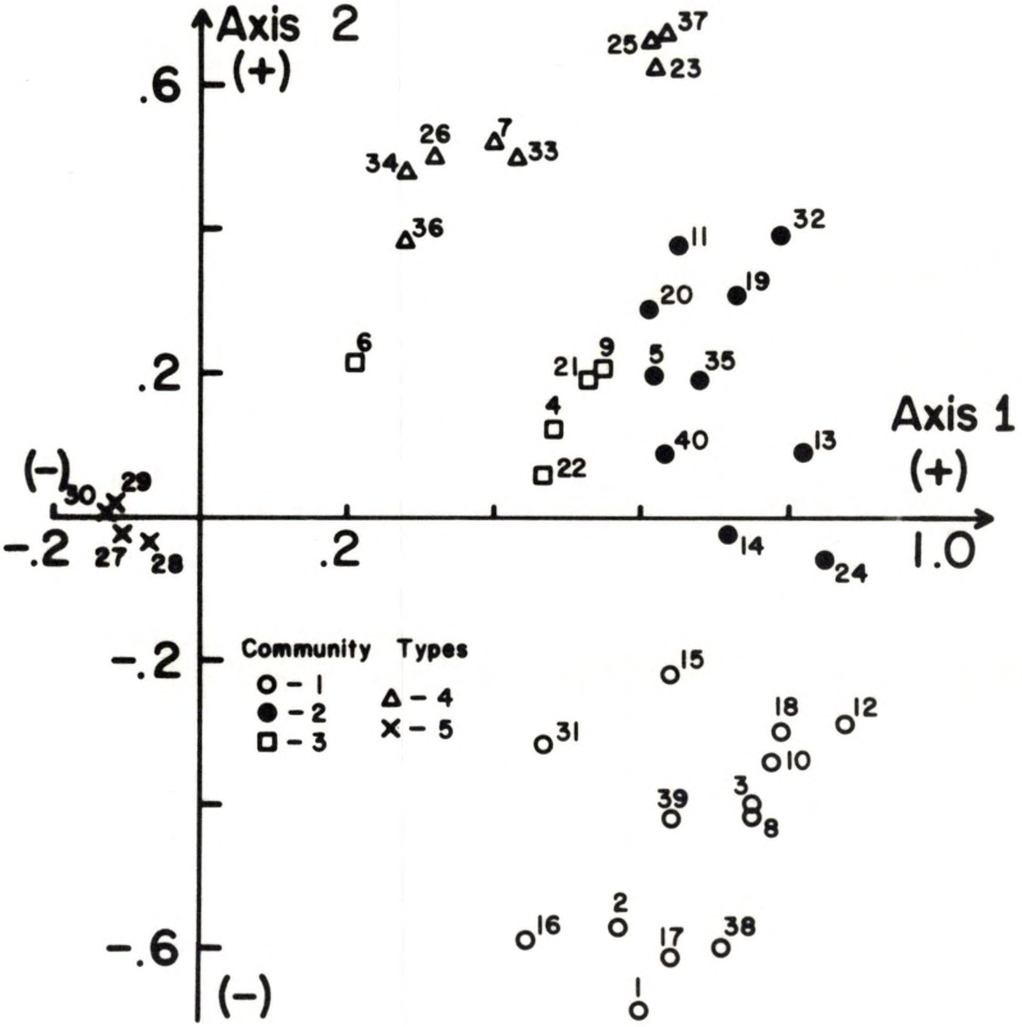

Axis 2
(+)
(-)
Axis 1
(+)
(-)
.6
.2
-.2
-.6
-.2
.2
1.0
Community Types
○ - 1
● - 2
□ - 3
△ - 4
× - 5
25
37
23
34
26
7
33
36
11
32
20
19
6
21
9
5
35
4
40
13
22
30
29
27
28
14
24
15
18
12
31
10
39
3
8
16
2
17
38
1

Fig. 6.--Position of 40 stands based on Swan-Dix-Wehrhahn ordination. Note the clustering of community types.

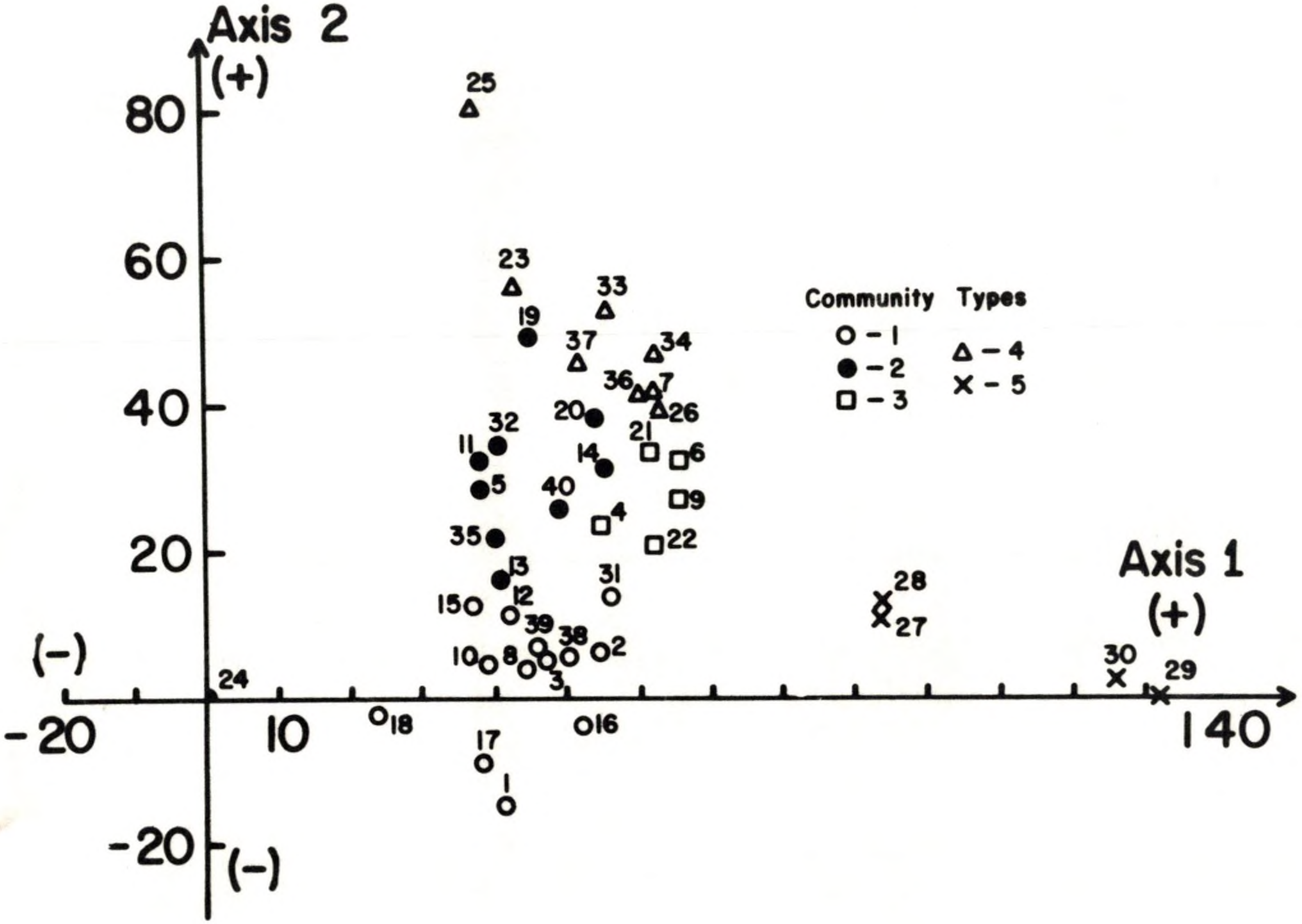

Axis 2
(+)
80
60
40
20
-20
(-)
Axis 1
(+)
(-)
-20
10
140
25
23
33
19
37
34
36
7
26
20
32
11
21
6
14
5
40
9
4
35
22
13
31
28
15
12
27
39
38
2
10
8
3
30
29
24
18
16
17
1
Community Types
○ - 1
● - 2
□ - 3
△ - 4
× - 5

TABLE 5

COMPARISON OF THE EFFECTIVENESS OF PRINCIPAL COMPONENT ANALYSIS (P.C.A.) AND SWAN-DIX-WEHRHAHN ORDINATION (S.D.W.O.) OF 40 STANDS

Ordination method	Axis 1	Axis 2	Axis 3	Total (3 axes)
P.C.A.	34.7[a]	14.6	7.4	56.7
S.D.W.O.	19.4[b]	14.6	10.6	44.6

[a] percentage variance accounted for by eigenvalues

[b] matrix extraction percentage

In Table 5 it is noted that principal component analysis accounts for about 15% more variance in the first axis and about 12% more of the total in the first three axes than Swan-Dix-Wehrhahn ordination. Moreover, comparison of Figures 5 and 6 reveals that principal component analysis produces more distinguishable groupings than Swan-Dix-Wehrhahn ordination. Therefore, based on these two criteria, the principal component analysis appears to be the more effective method in this study.

Relative coverage values of several species of representative vascular plants in each strata are shown in Figures 7, 8, 9, and 10. These figures give some indication of how a species is distributed in each type relative to all other types. As such, these are useful in describing the community types.

Fig. 7.--Relative coverage values of species in the A stratum in each community type (Q, *Quercus macrocarpa*; F, *Fraxinus pennsylvanica*; U, *Ulmus americana*; P, *Populus tremuloides*; B, *Betula papyrifera*; T, *Tilia americana*; A, *Acer negundo*).

Fig. 8.--Relative coverage values of selected species in the B_1 stratum in each community type (P, *Prunus virginiana*; A, *Amelanchier alnifolia*; Cc, *Corylus cornuta*; Ca, *Corylus americana*).

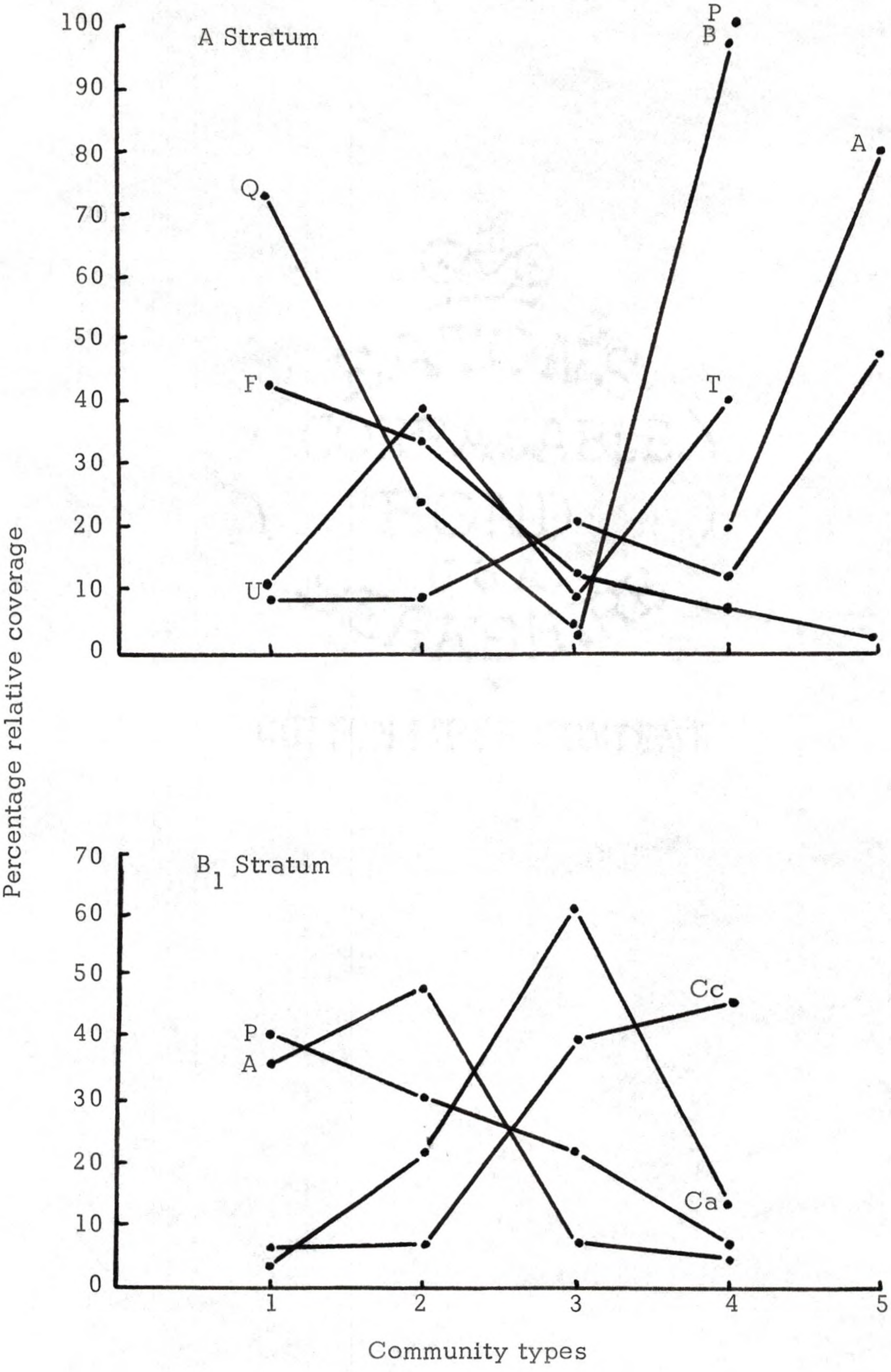
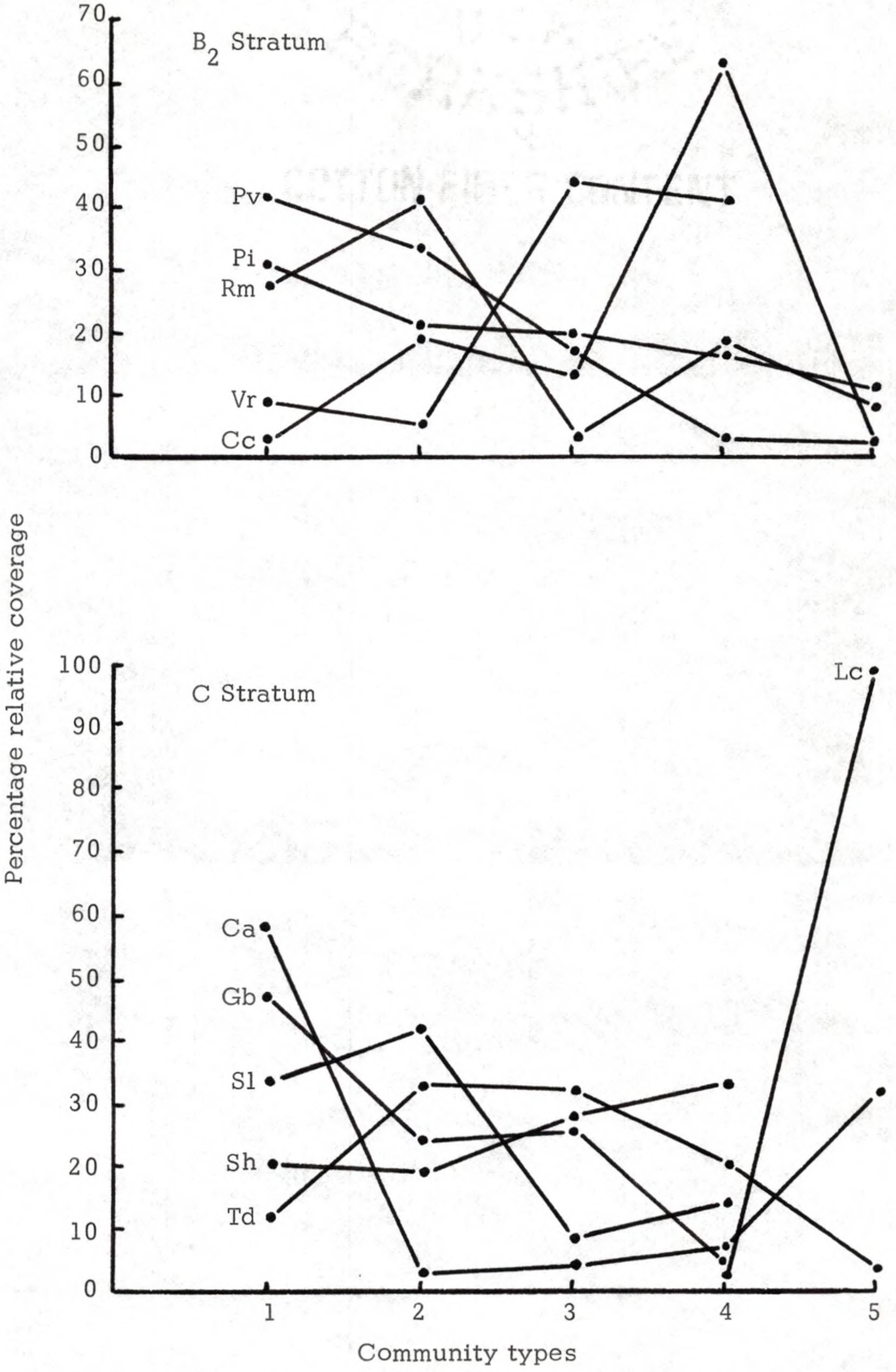

A Stratum
100
90
80
70
60
50
40
30
20
10
0
Q
F
U
P
B
T
A
B1 Stratum
70
60
50
40
30
20
10
0
P
A
Cc
Ca
1
2
3
4
5
Percentage relative coverage
Community types

Fig. 9.--Relative coverage values of selected species in the B_2 stratum in each community type (Pv, Prunus virginiana; Pi, Parthenocissus inserta; Rm, Ribes missouriense; Vr, Viburnum rafinesquianum; Cc, Corylus cornuta).

Fig. 10.--Relative coverage values of selected species in the C stratum in each community type (Ca, Carex assiniboinensis ; Gb, Galium boreale; Sl, Stellaria longifolia; Sh, Smilax herbacea; Td, Thalictrum dasycarpum).


B2 Stratum
70
60
50
40
30
20
10
0
Pv
Pi
Rm
Vr
Cc
Percentage relative coverage
C Stratum
100
90
80
70
60
50
40
30
20
10
0
Ca
Gb
Sl
Sh
Td
Lc
1
2
3
4
5
Community types

The present data on mosses and lichens is included both in the description of community types and in Table 1. Two species of mosses, Brachythecium sp. and Leskea arenicola are found in all community types and thus are not useful for diagnostic purposes. Leskea arenicola is the most ubiquitous moss. Similarly, the lichens Xanthoria fallax, Physcia stellaris, P. aipolia, and P. grisea are present in all types.

Community Type 1

The 13 stands representative of this type are located primarily on upper and middle south- and west-facing slopes. The slope angles range from 9 to 28°, with an average of 16°. Among the overstory species, bur oak has the highest absolute and highest relative (72.6%) coverage values here (Figure 7). Green ash also has a high absolute value and its highest relative coverage value (43.7%) in this type. Basswood and American elm are present, but have low coverage values. There are an average of 10.8 trees/100 m^2.

Prunus virginiana (chokecherry) and green ash reach their highest relative coverage values in both the B_1 and B_2 strata. Amelanchier alnifolia (Juneberry) has its highest relative coverage in the B_2 and a high value in the B_1. The low shrub, Symphoricarpos albus (snowberry), has its highest relative coverage value in this type.

Herbaceous plants, with high relative coverage values, consistently found in this type (Figure 11) include Anemone canadensis, Poa pratensis, Carex assiniboinensis, C. sprengelii, Fragaria virginiana, Galium boreale.

Fig. 11.--Ground cover vegetation showing Anemone canadensis, Galium boreale, Poa pratensis, and Lathyrus ochroleucus in a Quercus macrocarpa stand.

Lathyrus ochroleucus, and Smilacina stellata

There are no special patterns in distribution of mosses that help to distinguish this type from the others.

The lichen, Parmelia ulophyllodes, is restricted to this community type and to type 2.

Community Type 2

Unlike type 1, the 10 stands within this type are nearly all north and west facing. Similar to type 1, stands are located at upper and mid-slope positions. The slope angles range from 9 to 20°. The average of 13° is 3° less than for type 1.

The overstory consists of four species of trees. Arranged in decreasing order of absolute coverage value, these include basswood, bur oak, green ash, and American elm. None of these reach their highest relative cover value in this type, however, the value for basswood (39.2%) is close to the maximum. Tree density average for this type is 7.6 trees/100 m^2.

The shrub layer has a large representation of Corylus americana (American hazlenut) and C. cornuta (beaked hazlenut), although neither has its highest relative value in this type. Similar to type 1, choke-cherry and Juneberry have high absolute coverage values in both the B_1 and B_2 strata. The relative coverage value for Juneberry in the B_1 stratum (49.1%) is the highest among all types.

Ground-cover plants with high relative cover values, which set this type apart from others, include Aralia nudicaulis, Stellaria longifolia, Maianthemum canadense, Trillium cernuum, Oryzopsis asperifolia, O. racemosa, Thalictrum dasycarpum, and Zizia aurea. All have their highest relative coverage values in this type.

The general species composition of this type, including vascular plants, mosses, and lichens, is more similar to type 1 than any other type.

Community Type 3

The five stands representative of this type are located on middle slopes of north to northeast aspect. Slope angles range from 9 to 28°; the average is 10°.

Green ash and bur oak are the dominant trees. Relative to types 1 and 2, the coverage values of these species are low. Basswood and American elm are present, but not uniformly distributed among the stands. The average number of trees in a plot, 3.6, is the lowest of all community types.

Shrubs in the B_1 strata are principally American and beaked hazlenut. These species have their highest relative coverage value in this type. In the B_2, the liana, Vitis vulpina (wild grape), has its highest relative coverage value.

Only a small number of herbaceous plants have high enough relative coverage values to distinguish this type from the others. These include Smilacina stellata, Smilax herbacea, and Thalictrum dasycarpum.

Some of the herbaceous species found in this type are shown in Figure 12.

Campylium hispidulum and Pylaisiella polyantha, mosses present in types 1 and 2, and Physcia orbicularis, present in types 1, 2, and 4, were not present here. Also absent was Candelaria concolor, which occurs in all other types.

The general composition of the vegetation in this type makes it somewhat transitional between types 1 and 2 and type 4.

Community Type 4

All eight stands representative of this type are located on lower north-facing slopes. Slopes range from 6 to 32°. The average, 19°, is the highest among all types.

Basswood attains its highest coverage value here and is the dominant overstory species. Aspen is found only in this community type (Figure 13). Birch has a coverage value of 97.5% relative to other types. The presence of these two species clearly differentiates this type from the others. The density of trees is 8.2/100 m^2.

Associated with these overstory species are the shrubs Cornus stolonifera (red-osier dogwood), mainly restricted to this type, and American and beaked hazlenut. Vitis vulpina has coverage values nearly as high as in type 3.

The herbs Aralia nudicaulis, Aquilegia canadensis, Maianthemum canadense, Smilax herbacea, Trillium cernuum, and Galium triflorum all have high relative coverage values.

Fig. 12.--Trillium cernuum, Thalictrum dasycarpum, T. venulosum, Galium boreale, and Poa pratensis in a Quercus-Fraxinus-Ulmus stand.

Fig. 13.--Populus tremuloides canopy (plot 36).

The species composition of mosses is quite similar to types 1 and 2. Unlike other types, Mnium cuspidatum was recorded in every stand. The lichen species are the same as found in type 3. Like type 3, Parmelia ulophyllodes was not found here. Physcia orbicularis occurred in only one of the eight stands.

Community Type 5

The four stands within this type are all located on the floodplain. These stands slope slightly (1 to 3°) northward toward the Forest River. The dominant tree species are box elder and American elm. In these stands, box elder dominated in three stands, American elm in one. These two species have a relative coverage value of 80.0% and 46.9%. Tree density is 5.7 stems/100 m^2.

One of the conspicuous features of the floodplain vegetation in the plots studied is the general lack of shrubs. No species were recorded in the B_1 stratum. American elm, Ribes missouriensis (Missouri gooseberry), and Parthenocissus inserta (woodbine) are the only species in the B_2 found in more than one plot.

Two species of herbs, Galium aparine and Laportea canadensis, completely dominate the ground cover here (Figure 14). In addition to these, Leonurus cardiaca, Hydrophyllum virginianum, and Viola pennsylvanica have their highest relative coverage value in this type.

The striking contrast between species of vascular plants here and on the slopes is paralleled by that of the lichens and mosses. Only three

Fig. 14.--An Acer negundo stand on the floodplain with groundcover dominated by Galium aparine and Laportea canadensis.

species of mosses, *Brachythecium sp.*, *Campylium hispidulum*, and *Leskea arenicola*, are common. The lichens recorded here include *Xanthoria fallax*, *X. polycarpa*, *Candelaria concolor*, *Caloplaca aurentiaco*, *Physcia stellaris*, *P. aipolia*, and *P. grisea*.

The scarcity of species of vascular plants, mosses, and lichens distinguishes this type from all others.

Soil Morphology

Based on the 1960 U.S. Department of Agriculture system (7th Approximation), soil representative of the area and their respective parent materials are as follows: (1) Sioux Series (Entic Haploborolls) forming on beach ridge and glacial outwash sands and gravels, (2) Buse Series (Entic Haploborolls) on glacial-till, (3) Hecla Series (Pachic Haploborolls) on loamy sand eolian deposits, and (4) Fairdale Series (Typic Ustifluvents) on sandy alluvium. Results of this soil classification along with the near equivalence of soil subgroups in Canadian (National Soil Survey Committee of Canada, 1968) and UNESCO/FAO (Clayton, 1968) classifications for all 40 plots are shown in Table 6.

The soils of the Sioux Series are common on upper elevations; horizons are thin and poorly developed. The description of the soil profile from plot 8, representative of this series, follows:

Horizon	Description
O1	4 to 2 cm; loose layer of bur oak leaves with a few twigs,
O2	2 to 0 cm; dark; amorphous; 21.7% organic matter; pH 8.1,

TABLE 6

CLASSIFICATION OF SOILS STUDIED TO THE SUBGROUP LEVEL

U.S.D.A. (1960, 1967)[a]	U.S.D.A. (1938)[b]	Canadian (1965)[c]	UNESCO/FAO (1968)[d]	Plot No.
Entic Haploboroll (Sioux Series)	Regosol	Rego Dark Brown Chernozem	Haplic Castanozern	8, 9, 11, 14, 18
Entic Haploboroll (Buse Series)	Regosol	Rego Dark Brown Chernozem	Haplic Castanozern	1, 2, 4, 6, 7, 10, 12, 13, 19, 20, 24, 25, 26, 32, 33, 35, 36, 37
Pachic Haploboroll (Hecla Series)	Chernozem	Orthic Dark Brown	Haplic Castanozern	3, 5, 15, 16, 17, 21, 22, 23, 31, 34, 38, 39, 40
Typic Ustifluvent (Fairdale Series)	Alluvial	Orthic Regosol	Entric Rhegosols	27, 28, 29, 30

[a] U.S. Department of Agriculture (1960, 1967)

[b] U.S. Department of Agriculture (1938)

[c] National Soil Survey Committee of Canada (1965)

[d] World Classification UNESCO/FAO (Clayton, 1968)

Al	0 to 28 cm; very dark gray (10 YR 3/1) to black (10 YR 2/1 moist); sandy loam; granular; nonsticky, nonplastic; roots very abundant; wavy boundary; 4.1% organic matter; pH 7.7,
IIC	28 cm+ (rooting depth 46); pale brown (10 YR 6/3) to dark brown (10 YR 4/3 moist); sandy loam; structureless; nonsticky, nonplastic; roots very few to solitary; 0.9% organic matter; pH 7.4.

Soils of the Buse Series form on middle to lower slopes (Figure 15). Although horizons are not well developed, soils of this series show greater development than any others. The description of the soil profile in plot 1 is typical of this series:

Horizon	Description
O1	6 to 2 cm; loose layer of bur oak leaves and twigs,
O2	2 to 0 cm; dark and compact; mycelia present; 17.6% organic matter; pH 7.7,
Al	0 to 20 cm; dark gray (10 YR 4/1) to very dark gray (10 YR 3/1 moist); sandy clay loam; granular; nonsticky, nonplastic; roots very abundant; clear, wavy boundary; 3.4% organic matter; pH 7.8,
B2	20 to 45 cm; pale brown (10 YR 6/3) to brown (10 YR 5/3 moist); weakly developed; clay loam; prismatic; slightly sticky, slightly plastic; roots few to solitary; gradual, smooth boundary; 1.1% organic matter; pH 7.4,
Cca	45 cm+ (rooting depth 62); light yellowish brown (10 YR 6/4) to yellowish brown (10 YR 5/4 moist); clay loam; slightly sticky, slightly plastic; roots few to solitary; 1.2% organic matter; pH 7.6.

Soils of the Helca Series are common on south- and east-facing slopes, where prevailing winds have deposited thick layers of loess (Figure 16). Rooting depths of up to 78 cm were recorded in these soils. They have the deepest rooting depths of the four soil series. A description of plot 39 serves as an example:

Fig. 15.--An Entic Haploboroll under a Quercus-Fraxinus stand. Note the glacial-till parent material.

Fig. 16.--Pachic Haploboroll under a *Quercus*-*Fraxinus* stand. Note thick loess deposits.

Horizon	Description
O1	3 to 1 cm; loose layer of bur oak leaves and twigs,
O2	1 to 0 cm; dark and compact, 29.5% organic matter; pH 8.2,
A1	0 to 63 cm; very dark gray (10 YR 3/1) to black (10 YR 2/1 moist); sandy clay loam; crumb; nonsticky, nonplastic; roots abundant; clear, smooth boundary; 2.8% organic matter; pH 6.8,
C	63 cm+ (rooting depth 70); dark gray (10 YR 4/1) to very dark gray (10 YR 3/1 moist); sandy loam; structureless; nonsticky, nonplastic; roots few to solitary; 0.8% organic matter; pH 6.6.

Restricted to the floodplain, soils of the Fairdale Series, like the Sioux, are poorly developed. A significant feature of this series is the shallow rooting zone. Rooting depths, as little as 17 cm, are the shallowest of the four series. The soil profile description of plot 29 is representative of this series:

Horizon	Description
O1	2 to 0.5 cm; loose; discontinuous layer of box elder leaves,
O2	0.5 to 0 cm; dark compact; 11.7% organic matter; pH 8.1,
A1	0 to 17 cm; dark gray (10 YR 4/1) to very dark gray (10 YR 3/1 moist); sandy clay loam; crumb; slightly sticky, slightly plastic; roots few; clear, smooth boundary; 8.6% organic matter; pH 7.9,
C	17 cm+ (rooting depth 37); dark gray brown (10 YR 4/2 to very dark gray brown (10 YR 3/2 moist); sandy loam; structureless; nonsticky, nonplastic; charcoal present; roots very abundant; 2.2% organic matter; pH 7.7.

Physical Characteristics of Soil

Tables showing in detail the physical properties of each horizon for all 40 stands are presented in Appendix B. The main features of these physical properties will be discussed in this section. Bulk density, the weight of a unit volume of soil in its natural structure, is an important physical property of soil. Its value is necessary for calculating amount of soil water on a weight or volume basis. Bulk density of soils studied ranged from a low of 0.48 in the A horizon of stand 15 to a high of 1.35 in the C horizon in stand 27. Sandy soils tend to have slightly higher bulk densities than those with finer texture.

Soil particle size does not vary greatly between A and B horizons in the 40 plots. Texture classes in these horizons include sandy loam, sandy clay loam, and clay loam. In the C horizons an additional texture class, sand, is present. Most of A, B, and C horizons are sandy loams where parent material consists of beach sand and sandy clay loam where parent material is glacial-till.

Differences in soil structure and texture strongly influence the water retention capacity of soils. The 1/3 bar level, as determined in the laboratory, approximates the field water capacity. A comparison between 1/3 bar values and actual field water levels shows there is no significant correlation between them in the A and B horizons. However, a statistically significant correlation coefficient at the 0.01 level (r=0.614) exists between field water and 1/3 bar in the C horizons. The upper horizons are more variable in water available for plant growth. These horizons are wet after rainy periods, but become very dry late in the summer. Available soil water levels in plots 1, 14, and 23 measured from June 10 to October 15, 1971, (Figure 17) illustrate this point. A

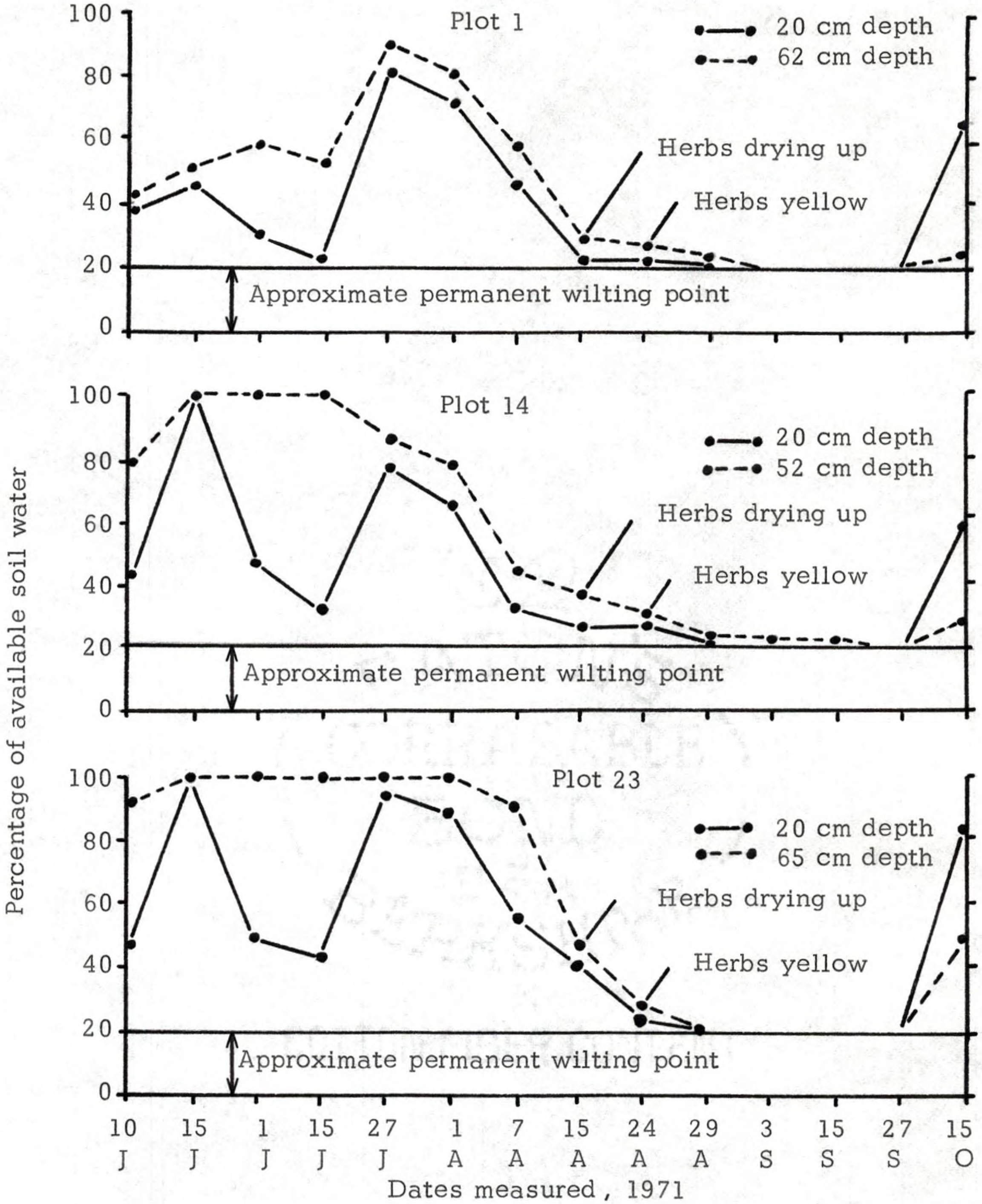
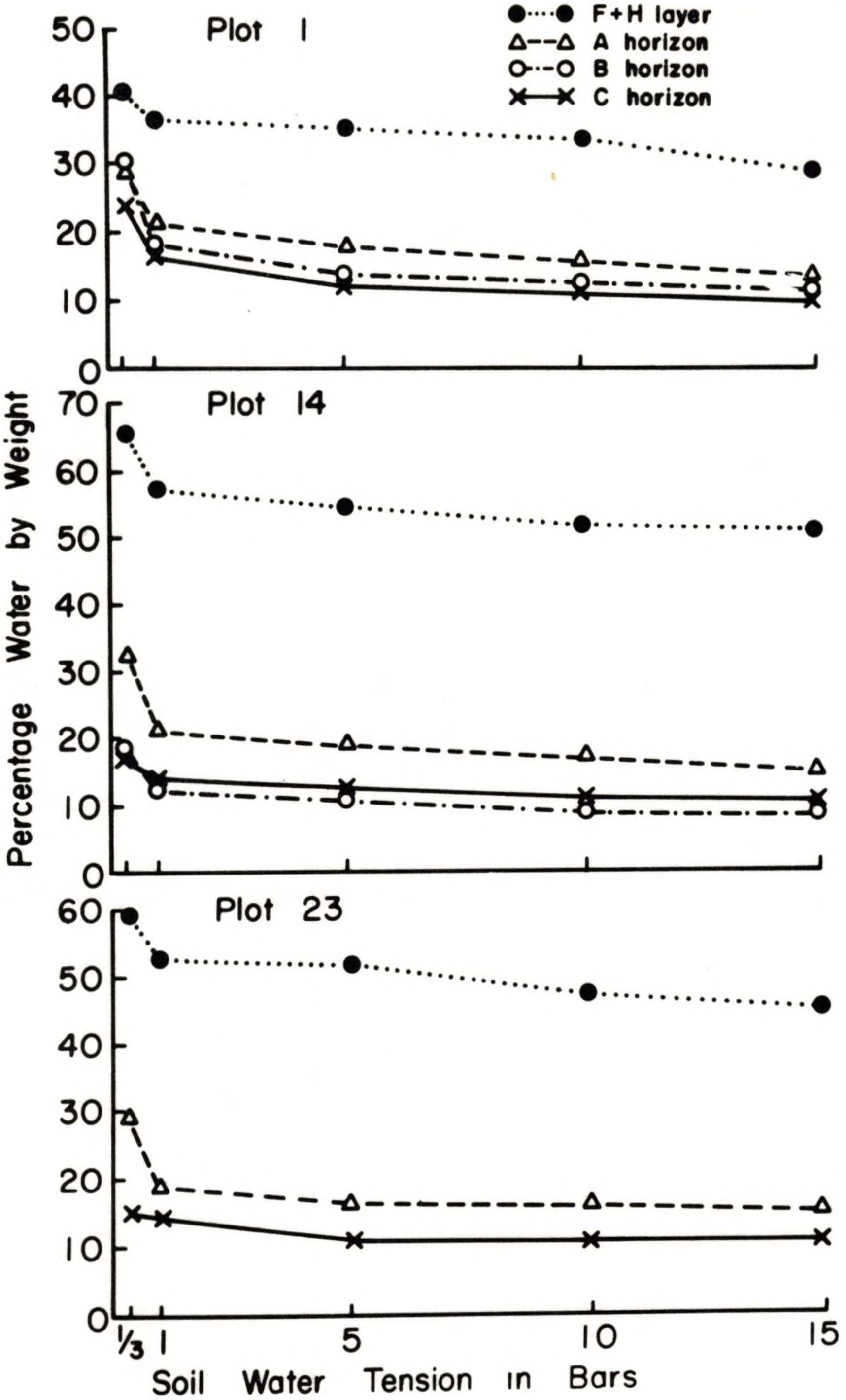


Fig. 17.--Percentage available water at two soil depths: 20 cm and maximum rooting depth in plots 1, 14, and 23.

definite lag is noted between the amounts of available soil water in surface and subsurface horizons. A marked decrease in soil water occurred in mid-August. Around this time, herbaceous plants began to turn yellow and to dry up. This phenomenon was not observed until early September during the 1970 growing season. This suggests that in 1971, herbaceous plants were under stress due to drought conditions and not to a change in photoperiod.

Further insight into the soil-water relationships of these three stands is gained by plotting the percentage water by weight at 1/3, 1, 5, 10, and 15 bars for each horizon. Water depletion curves based on this data are presented in Figure 18. Because specific conductivity values are low for these soils and pH is nearly neutral, the diffusion pressure deficit, due to the osmotic concentration of soil solutes in the soil solution, is negligible (Wadleigh, 1946). Therefore, the total soil water stress is attributable to the soil water tension (matric potential). A comparison between the water retention capacity (taken as a difference between 1/3 and 15 bars) within each mineral subsurface horizon reveals lower levels in plots 14 and 23. This difference is due to the higher content of sand in these two soils. A higher organic matter content in plots 14 and 23 however, offsets this difference in the A horizons where plot 14 has more than and plot 23 the same level of available water as plot 1. In all horizons in the three plots a large amount of water is available to plants between 1/3 and 1 bar. The water content decreases as the soil water tension increases and there is a considerable decrease

Fig. 18.--Soil water depletion curves for plots 1, 14, and 23.


Plot 1
Plot 14
Plot 23
●····● F+H layer
△--△ A horizon
○-·-○ B horizon
×—× C horizon
Percentage Water by Weight
50
40
30
20
10
0
70
60
50
40
30
20
10
0
60
50
40
30
20
10
0
1/3
1
5
10
15
Soil Water Tension in Bars

beyond the 5 bar level. Thus, contrary to the concept proposed by Veihmeyer (1956) and Veihmeyer and Hendrickson (1950), the amount of water available to plants in these soils is not equally available at all levels between 1/3 and 15 bars (see Stanhill, 1957). Moreover, the differences in percentage water by weight among horizons within the same profile, particularly at the 1/3 bar level, show the importance of measuring the water retention levels in each genetic horizon separately.

Chemical Properties of Soil

A complete analysis of the chemical properties of soils within the Biology Area is reported in Appendix B. A summary of these properties is included in the following discussion.

The humus is slightly alkaline; for example, pH ranges from 7.4 to 8.4. Mineral horizons are nearly neutral with a pH range of 6.1 to 7.9. As a rule, humus and mineral horizons forming on glacial-till parent material have higher pH levels than those forming on sand or where large amounts of loess are present. The pH values obtained with 0.01 molar $CaCl_2$ were consistently lower than those obtained with the water soluble fraction. In most cases, they were about one pH unit lower.

The electrical conductance, an expression of total soluble salt concentration, varies considerably among the plots. Humus layers have the highest values, ranging from 241 to 1380 micromhos/cm. Mineral horizons have values from 52 in the C horizon of plot 13 to 741 micromhos/cm in the A horizon of plot 27. Conductivity of the humus and mineral horizons on the floodplain, particularly plots 27 and 28, is generally higher than those on the slopes. Among soils on the slopes, those originating from glacial-till have the lowest conductivity values.

Similar to conductivity values, the range of the cation exchange capacities of the humus layers and mineral soils in floodplain plots 27 and 28 (17.6 to 280.0 meq/100 g) are among the highest in all stands. These high values may be attributed to two factors. First, periodic flooding results in deposition of silt, clay, and organic matter, responsible for enrichment in chemical elements. Secondly, unlike the other two (29, 30) floodplain plots, plots 27 and 28 lie on a small slopewash fan. This fan receives enrichment in the form of clays and organic matter from the slopes above.

Cation exchange capacity among all plots ranges from 6.3 meq/100 g in the sandy C horizon of plot 14 to 152.6 meq/100 g in the A horizons of plots 24 and 25. Humus values vary from 92.6 to 280.0 meq/100 g.

Organic matter, an expression of biomass production, shows a marked decrease with profile depth. In the humus layer, organic matter ranges from 4.1 to 33.2%. The low value (4.1%) is probably due to the presence of mineral soil in some of the samples. In a few plots, the humus layers were so thin that it was nearly impossible to collect humus without some contamination by underlying mineral soil. The levels of organic matter in the mineral soils are as follows: (1) A horizon, 1.5 to 11.6%; (2) B horizons, 0.6 to 2.4%; and (3) C horizons, 0.1 to 2.2%.

The chemical elements as studied can be divided into two basic groups: (1) replaceable and water soluble and (2) available. The four major cations, calcium, magnesium, potassium, and sodium, are included in the first group with phosphorus and trace metals in the second group. Values for all of these are given in Appendix B.

Emphasis here is placed on levels of replaceable rather than water soluble cations because they better approximate nutrients, readily and potentially, available for plant growth. The order of replaceable cations, in decreasing magnitude, in the soils is as follows: calcium, magnesium, potassium, and sodium. Levels of calcium range from 2.4 to 40.4 meq/100 g in the mineral horizons and from 12.0 to 26 meq/100 g in the humus layers. Magnesium values are not as variable as calcium. The highest levels (3.25 to 7.10 meq/100 g), in general, occur in the humus layers. The level in the mineral horizons is from 1.0 to 4.5 meq/100 g. The potassium levels vary in the mineral horizons from 0.28 meq/100 g to a high of 2.19 meq/100 g in a surface horizon. Levels in the humus range from 1.05 to 2.24 meq/100 g. The sodium levels closely parallel those of potassium and range from 0.10 to 2.1 meq/100 g in all horizons.

Among the group of elements which include phosphorus and the trace elements, the amounts present from highest to lowest levels reveal a pattern as follows: manganese, iron, aluminum, silicon, phosphorus, zinc, nickel, copper, lead, and strontium. However, in a few soils, silicon levels are very high (up to 3916 ppm). A general decrease in the level of the EDTA-extractable trace elements in lower horizons is attributable to a decline in organic matter.

Phosphorus values range from 1 ppm in surface horizons to 94 ppm in one humus sample. On the slopes, levels are generally lower in the humus at upper elevations and higher at lower elevations, whereas levels on the floodplain, in both the humus and mineral horizons, are relatively low.

A general pattern of manganese distribution exists with lowest levels present on the floodplain and in soils originating on glacial-till parent material. Highest levels exist in soils where loess deposits are present. Manganese levels range from 80.5 ppm in the C horizon of plot 1 to 2003 ppm in the humus layer of plot 31.

Although iron levels are higher, the levels of iron and aluminum closely parallel each other in most soils. The range for iron is from 25.5 to 774 ppm in C horizons of plots 1 and 9, respectively. The amount of aluminum present shows a general increase with soil depth ranging from 5 ppm in a humus layer to 574 ppm in a subsurface horizon.

The range of silicon among all horizons is the greatest for all elements. Levels are generally low in soils forming from glacial till and high where loess deposits are present. The extremes, both found in subsurface horizons, are 30 ppm and 3916 ppm.

The range of values in parts per million for the remaining elements including humus and mineral horizons is as follows: (1) zinc, 1.55 to 85.8; (2) nickel, 2.0 to 16.8; (3) copper, 1.0 to 11.5; (4) lead, 1.0 to 13.5; and (5) strontium, 0.0 to 2.55. In several B and C horizons no strontium was detected. However, strontium as well as manganese were detectable in some horizons and therefore measured in 1 normal ammonium acetate extractions for all horizons. The ranges of these two elements in humus and mineral horizons are compared with EDTA-extraction in Table 7. From this table it is apparent that strontium as compared to manganese, is much more readily extracted with ammonium acetate. Wali and Krajina (1972) and Wali, Gruendling and Blinn (1972) have reported similar results and attribute this differential behavior of strontium to its incomplete chelation with EDTA. They feel that most of the strontium present in soils may be lodged on the exchange complex.

TABLE 7

STRONTIUM AND MANGANESE LEVELS (ppm) IN AMMONIUM ACETATE AND EDTA EXTRACTIONS

Horizon	Humus	A	B	C
		Strontium		
Ammonium acetate-extractable	7.9- 13.9	5.5- 15.9	3.2- 6.3	1.9- 7.5
EDTA-extractable	0.1- 2.4	0.3- 2.0	0.0- 2.3	0.0- 2.5
		Manganese		
Ammonium acetate-extractable	10.3- 93.6	0.5- 15.0	0.8- 17.6	0.6- 7.4
EDTA-extractable	308.0-2003.5	174.5-1136.5	159.5-763.0	80.5-1024.5

Stepwise Multiple Regression

Of the initial 50 species used for multiple regression analysis, three species failed to yield any independent variable with a statistically significant T-value. Comparison between the multiple correlation (R) values obtained by using transformed and untransformed data for the remaining species are shown in Table 8.

TABLE 8

CHANGES IN MULTIPLE CORRELATION VALUES AS A RESULT OF LOGARITHMIC TRANSFORMATION OF SELECTED INDEPENDENT VARIABLES

Stratum	No. increased	No. decreased	No. with no change
A (trees)	6	1	0
B (shrubs)	8	11	3
C (herbs)	11	7	0
Totals	25	19	3

Slightly more than one-half of the regressions show an increase in the multiple correlation after logarithmic (base 10) transformation. Among the different strata, the increase in the multiple correlation as a result of log transformation is prevalent in tree species (88%) and herb species (61%). For shrub species, only 36% have higher multiple correlation values with transformed independent variables, while 14% show no change at all.

Based on the regression with the highest multiple correlation from either the transformed or untransformed variables, a multiple regression equation was selected to represent each of the species. From these, those with multiple R^2 (coefficient of determination) of 0.22 or higher were selected as illustrative models. The coefficient of determination represents as a decimal fraction, the percentage of the variance accounted for by multiple regression. Thus, all regression models presented account for 22% or more of the variance in presence-absence that can be accounted for. These models, presented in Table 9 follow the general equation

$$Y = a+b_1X_1+b_2X_2\ldots b_nX_n\underline{+}SE,$$

where:

Y = dependent variable (criterion),
a = Y intercept,
b = partial regression coefficient,
X = independent variable (predictor), and
Se = standard error of the estimate.

Each of the environmental variables are retained within the regressions, although some occur more frequently than others. Table 10 shows the frequency of occurrence of these environmental parameters. This frequency was determined from the one member of each of transformed-untransformed pairs with the highest multiple R.

Analysis of Table 10 reveals a different environmental variable occurs most frequently in each stratum. The most frequently retained variable(s) for the tree layer is available water capacity, for the shrub layer is potential solar beam irradiation, and for the herb layer are

TABLE 9

MULTIPLE REGRESSION EQUATIONS FOR PREDICTING PRESENCE-ABSENCE OF SELECTED SPECIES BY ENVIRONMENTAL PARAMETERS (LINEAR AND LOG TRANSFORMATIONS)

Species	Regression equations
A Stratum	
Acer negundo	Y = -2.34-log1.125Ca-log.725Fe+log1.334AWC[a]+log.530%OM[b]±.241 (R=.741)
Betula papyrifera	Y = 9.954-log.767Mg+log1.005AWC-log4.176PSBI[c]±.155 (R=.621)
Fraxinus pennsylvanica	Y = -4.243-.172K+.002Fe+.024PSBI+.050S[d]-.009A[e]±.433 (R=.828)
Populus tremuloides	Y = -4.658-log1.457Mg+log1.251AWC+.017elev.±.155 (R=.828)
Quercus macrocarpa	Y = -1.344+log1.887Mg+log.597Mn-log2.014AWC-log.697%OM+.005A±.326 (R=.784)
Tilia americana	Y = 13.237+log.491P+log.658Zn-log.867Fe-log5.136PSBI±.423 (R=.604)
Ulmus americana	Y = 4.211+log.883K+log.739%OM-.015elev.±.317 (R=.537)
B_1 Stratum	
Corylus americana	Y = -19.017+log1.859K+log8.017PSBI-.007A±.428 (R=.499)
C. cornuta	Y = 1.624+log1.308K+log.540P-log.979Mn-.004A±.377 (R=.749)
Prunus virginiana	Y = .410-.022Zn+.024S±.469 (R=.475)
Tilia americana	Y = -11.983+log.742Mn-log.882Zn+4.759PSBI±.268 (R=.638)
B_2 Stratum	
Corylus cornuta	Y = 1.165-log1.830Mg+log2.166K±.415 (R=.567)
Fraxinus pennsylvanica	Y = -2.125-.036Mg+.027Zn-.013PSBI+.016elev.+.008A±.371 (R=.666)
Lonicera dioica	Y = .738+log.576P-log.774Zn±.379 (R=.645)
Prunus virginiana	Y = -.858+log1.145Ca+log.576Fe-log1.200AWC±.369 (R=.544)
Rhus radicans	Y = -5.328+.002Fe-.087AWC+.011elev.[f]+.035S±.258 (R=.613)
Symphoricarpos albus	Y = -3.029-.081K+.017Zn-.010%si+cl-.012PSBI+.019elev.+.020S+.005A±.204 (R=.833)

TABLE 9--Continued

Species	Regression equations
C Stratum	
Anemone canadensis	Y = -4.193+.009Ca+.088AWC-.105%OM+.013elev.-.026S±.334 (R=.703)
Aralia nudicaulis	Y = -4.738+.013P.-001Mn+.043Zn-.082AWC-.072%OM+.017elev.-.005A±.214 (R=.915)
Carex assiniboinensis	Y = -.079-.113K+.030%si+cl+.032%OM±.486 (R=.696)
C. pennsylvanica	Y = -.537-.018PSBI+.015 elev.+.007A±.334 (R=.610)
C. sprengelii	Y = .400-log1.427K+log.667Fe+.003A±.354 (R=.658)
Galium aparine	Y = 4.625-log.368Fe+log.941%si+cl-.014elev.-022S-.002A±.180 (R=.884)
Galium boreale	Y = -.342+.099Mg-.157AWC+.077%OM±.342 (R=.678)
Oryzopsis asperifolia	Y = 6.376-log1.086%OMlog5.298PSBI+.021elev.+.009A±.377 (R=.637)
Poa pratensis	Y = 1.559+log1.393Mg-log1.715%si+cl±.419 (R=.590)
Smilacina stellata	Y = -10.224+log2.078K-log.734Zn+log4.314PSBI±.417 (R=.606)
Thalictrum venulosum	Y = -16.132+log.795%OM+log6.884PSBI+.023S±.393 (R=.581)
Viola papilionacea	Y = -5.421+log1.023Ca-log.448Fe+.015elev.+.004A±.405 (R=.641)
V. pennsylvanica	Y = -8.093+log1.508%si+cl-log.982AWC+log2.880PSBI±.332 (R=.560)
V. rugulosa	Y = -16.594+log.905K+log7.058PSBI±.405 (R=.593)

---

[a] AWC represents available water capacity within rooting depth

[b] %OM represents weighted average percentage organic matter in rooting depth

[c] PSBI represents potential solar beam irradiation

[d] S represents slope angle

[e] A represents linear aspect

[f] %si+cl represents weighted average percentage silt+clay within the rooting depth

TABLE 10

FREQUENCY OF OCCURRENCE OF THE 14 INDEPENDENT VARIABLES RETAINED IN 47 MULTIPLE REGRESSIONS

Rank (based on total)	Independent variable	Frequency of occurrence			
		trees (7)[a]	shrubs (22)	herbs (18)	Total
1	PSBI	3	9	6	18
2	AWC	4	7	5	16
3	Elevation	3	5	7	15
4	Linear aspect	2	5	7	14
5	Slope	1	5	6	12
5	K	2	4	6	12
7	Mg	3	5	2	10
7	Zn	1	7	2	10
9	%OM	3	0	6	9
10	Fe	3	2	3	8
11	%si+cl	0	1	5	6
11	Mn	1	4	1	6
13	P	1	2	2	5
14	Ca	1	1	2	4

[a] numbers in parentheses indicate number of regressions for the stratum

elevation and linear aspect. The overall pattern based on the total number of regressions shows four non-nutrient parameters occur most frequently. These include three that are essentially topographic (potential solar beam irradiation, elevation, and linear aspect) and available water capacity which is a physical property of soil. The nutrient variable most frequently retained by regression analysis was potassium. Further analysis of the equations show potassium appears with a positive regression coefficient in 75% of the regressions. On the other hand, magnesium and zinc occur less frequently than potassium and had positive signs in 40 and 50% of the regressions coefficients, respectively. The frequent occurrence of negative regression coefficients for these two nutrients makes their value as predictors somewhat questionable (see Waring and Major, 1964). Based on these reasons, the first six parameters (potential solar beam irradiation through potassium) were considered to be the most reliable in predicting presence-absence for the greatest number of species.

Distribution of Species Along the Gradients

Based on the frequency of their selection by multiple regression analysis, the six environmental parameters potential solar beam irradiation, available water capacity, elevation, linear aspect, slope, and potassium were used to establish environmental gradients. The characteristics of the six gradients are shown in Tables 11, 12, 13, 14, 15, and 16. Each gradient was subdivided into five groups and each of these assigned an index number according to its position along the gradient. Thus, the group with the lowest values was assigned an index number of one and those with the highest values, an index number of five. Using gradient values, an attempt was made to divide the 40 stands into five groups of eight each. Because of a lack of natural breaks at these precise intervals, this was not always possible.

Using coverage values, ecological modalities of individual species were established along appropriate gradients as determined by multiple regression analysis. Ecological optimum, adopted from Waring and

TABLE 11

CHARACTERISTICS OF POTENTIAL-SOLAR-BEAM-IRRADIATION GRADIENT (PSBI)

Group	Group limits of potential solar beam irradiation gradient (PSBI)	Average of the group	No. stands in the group	Average no. of species in the group
I	0.0- 64.0	58.6	8	26.8
II	64.1- 70.0	66.7	7	24.6
III	70.1- 80.0	76.3	8	33.4
IV	80.1- 90.0	85.3	9	21.6
V	90.1-100.0	94.9	8	26.8

TABLE 12

CHARACTERISTICS OF THE AVAILABLE WATER GRADIENT (AWC) rd

Group	Group limits of available water capacity (AWC) rd	Average of the group	No. stands in the group	Average no. of species in the group
I	0.0- 36.0	30.5	9	23.6
II	36.1- 42.0	39.2	7	26.0
III	42.1- 53.0	49.4	9	22.9
IV	53.1- 63.0	58.5	7	28.9
V	63.1-100.0	80.9	8	32.4

TABLE 13

CHARACTERISTICS OF THE ELEVATIONAL GRADIENT

Group	Group limits of elevation gradient	Average of the group	No. stands in the group	Average no. of species in the group
I	0.0- 95.0	93.6	7	19.0
II	95.1- 96.4	95.8	9	31.4
III	96.5- 97.8	97.1	6	30.2
IV	97.9- 98.7	98.3	9	28.2
V	98.8-100.0	99.4	9	23.3

TABLE 14

CHARACTERISTICS OF THE LINEAR ASPECT GRADIENT

Group	Group limits of linear aspect gradient	Average of the group	No. stands in the group	Average no. of species in the group
I	0.0- 1.0	0.6	8	26.5
II	1.1- 15.0	14.3	6	25.2
III	15.1- 29.0	28.6	8	19.8
IV	29.1- 58.0	50.0	10	32.6
V	58.1-100.0	87.5	8	27.9

TABLE 15

CHARACTERISTICS OF THE SLOPE INCLINATION GRADIENT

Group	Group limits of slope inclination gradient	Average of the group	No. stands in the group	Average no. of species in the group
I	0.0- 29.0	16.3	9	18.7
II	29.1- 41.0	35.0	9	27.1
III	41.1- 54.0	48.4	8	23.6
IV	54.1- 79.0	67.7	6	30.7
V	79.1-100.0	85.9	8	33.5

TABLE 16

CHARACTERISTICS OF THE AVAILABLE POTASSIUM GRADIENT (AN-K) rd

Group	Group limits of available potassium (AN-K) rd gradient	Average of the group	No. stands in the group	Average no. of species in the group
I	0.0- 39.0	31.8	8	20.2
II	39.1- 48.0	43.6	9	25.9
III	48.1- 58.0	52.9	8	26.8
IV	58.1- 73.0	66.7	8	28.6
V	73.1-100.0	86.5	7	32.3

Major (1964), is the point at which maximum population density occurs along a selected gradient. The strength in this method of selection is that each gradient is known to contribute a significant independent portion of the variation associated with each species.

From a number of potential species that could be used for illustrative purposes, as many as possible with unimodal distribution along each gradient were selected in the belief that these were responding more strongly to the gradient than those showing distinct bimodal distributions. This is another check to ensure the selection of the appropriate gradients responsible for the distribution of the species. It should not, however, be construed that other gradients do not come into play, but only that some variables may have an overriding influence over others for a particular species in a given space at a particular time. Furthermore, by plotting the actual coverage values rather than presence-absence, as used for multiple regression analysis, a more realistic and meaningful pattern emerges.

Based on coverage values, the distribution of selected species along the gradients are illustrated in Figures 19, 20, 21, 22, 23, and 24. These diagrams should provide some autecological information on ecological modality and amplitude for each species. Examination of these diagrams reveals some species have a wide, and others a narrow amplitude along a particular gradient. In addition, ecological optima vary considerably. An example of this is the distribution of <u>Galium aparine</u> and <u>Prunus virginiana</u> along the AWC gradient (Figure 20). <u>Galium aparine</u>, restricted

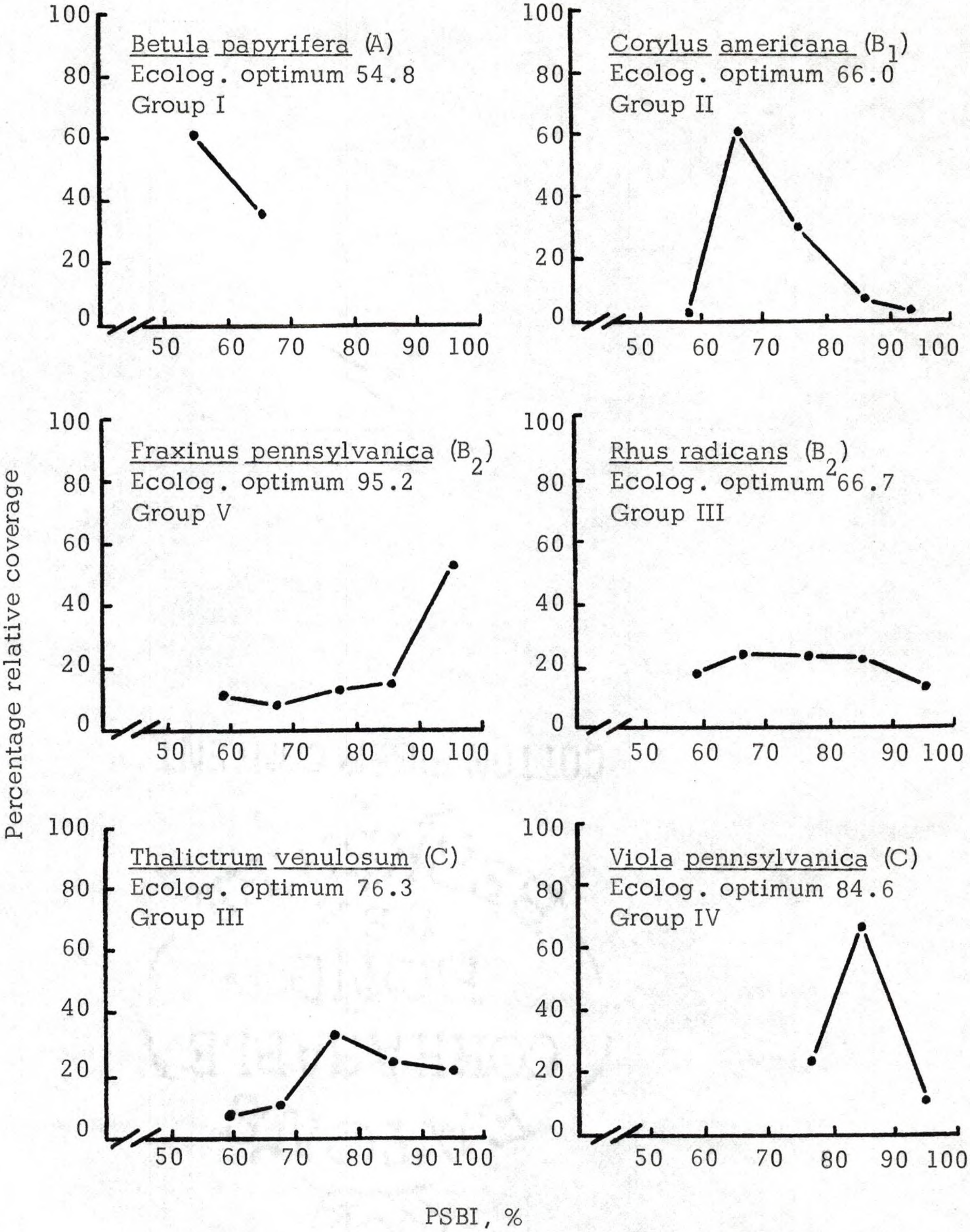


Fig. 19.--Distribution of selected species along the potential solar beam irradiation (PSBI) gradient.

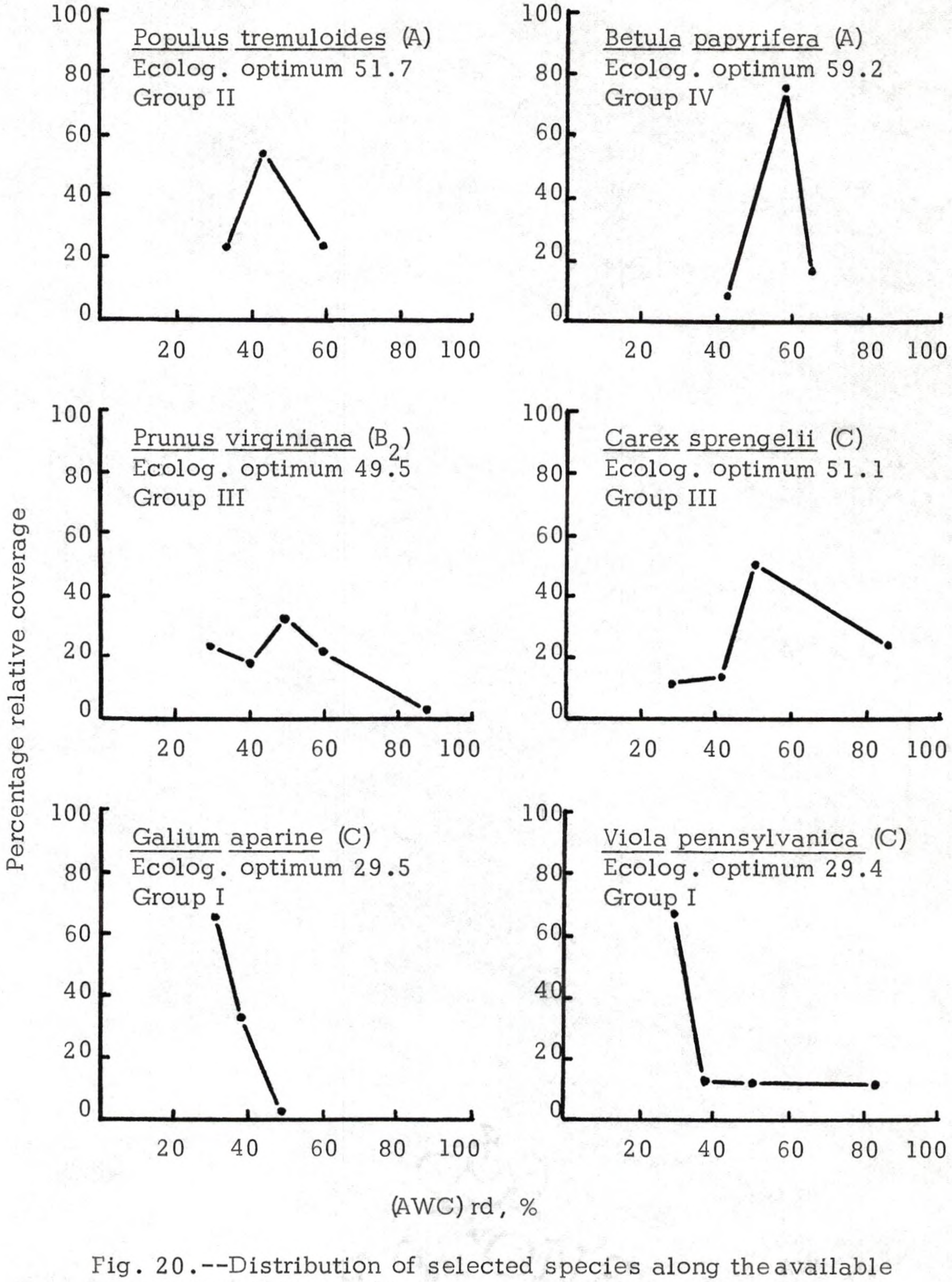


Fig. 20.--Distribution of selected species along the available water capacity (AWC)rd gradient.

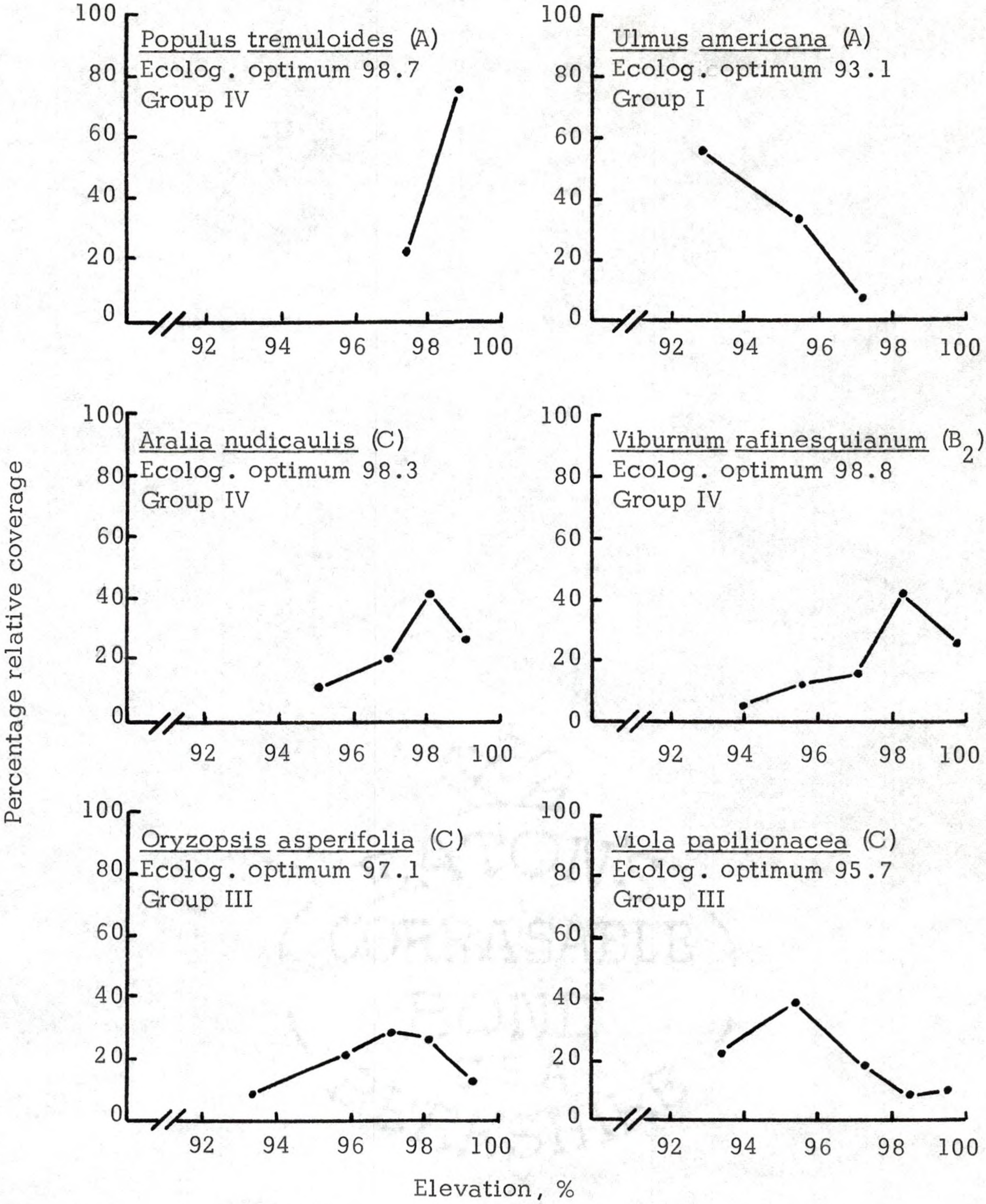


Fig. 21.--Distribution of selected species along the elevation gradient.

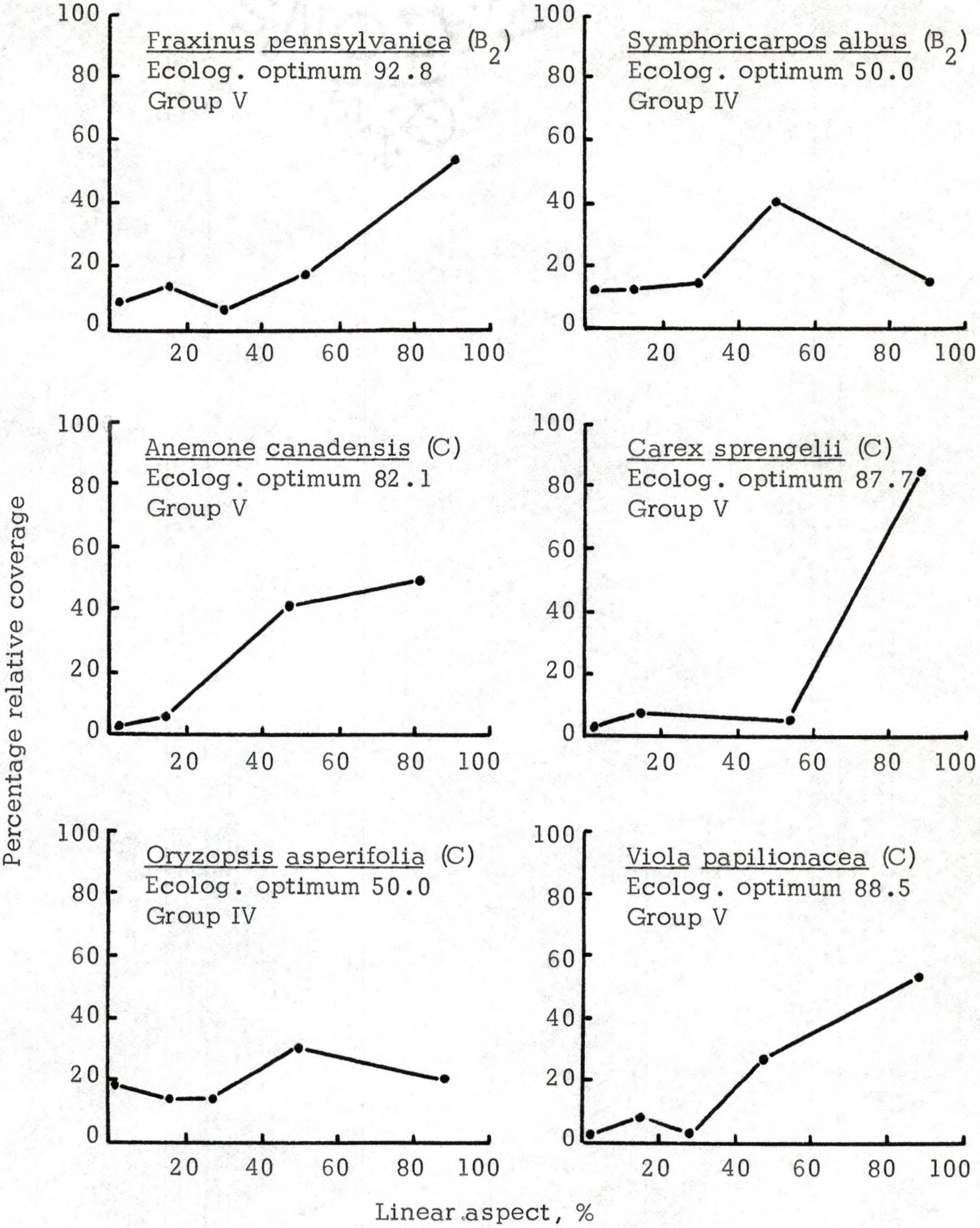


Fig. 22.--Distribution of selected species along the linear aspect gradient.

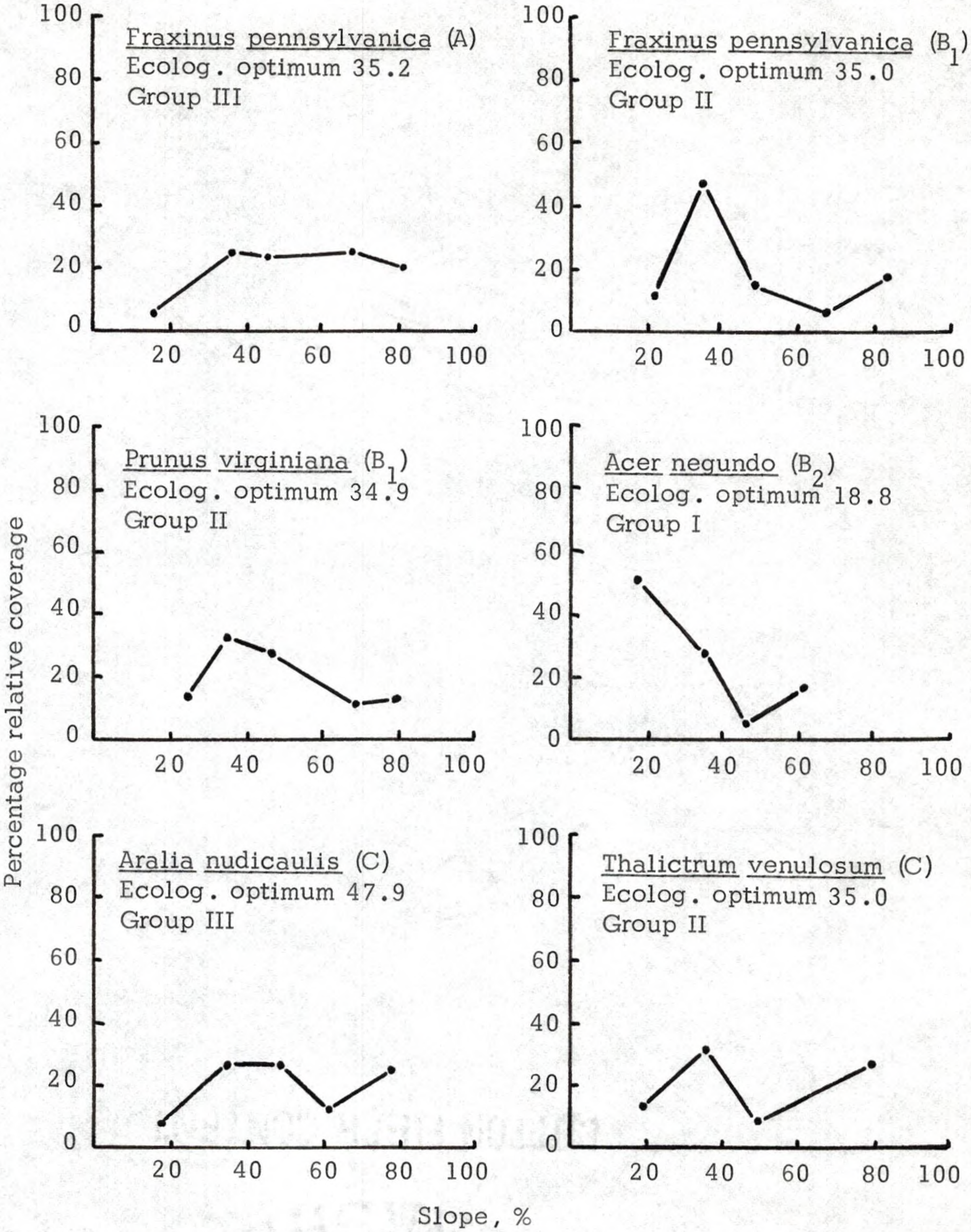


Fig. 23.--Distribution of selected species along the slope gradient.

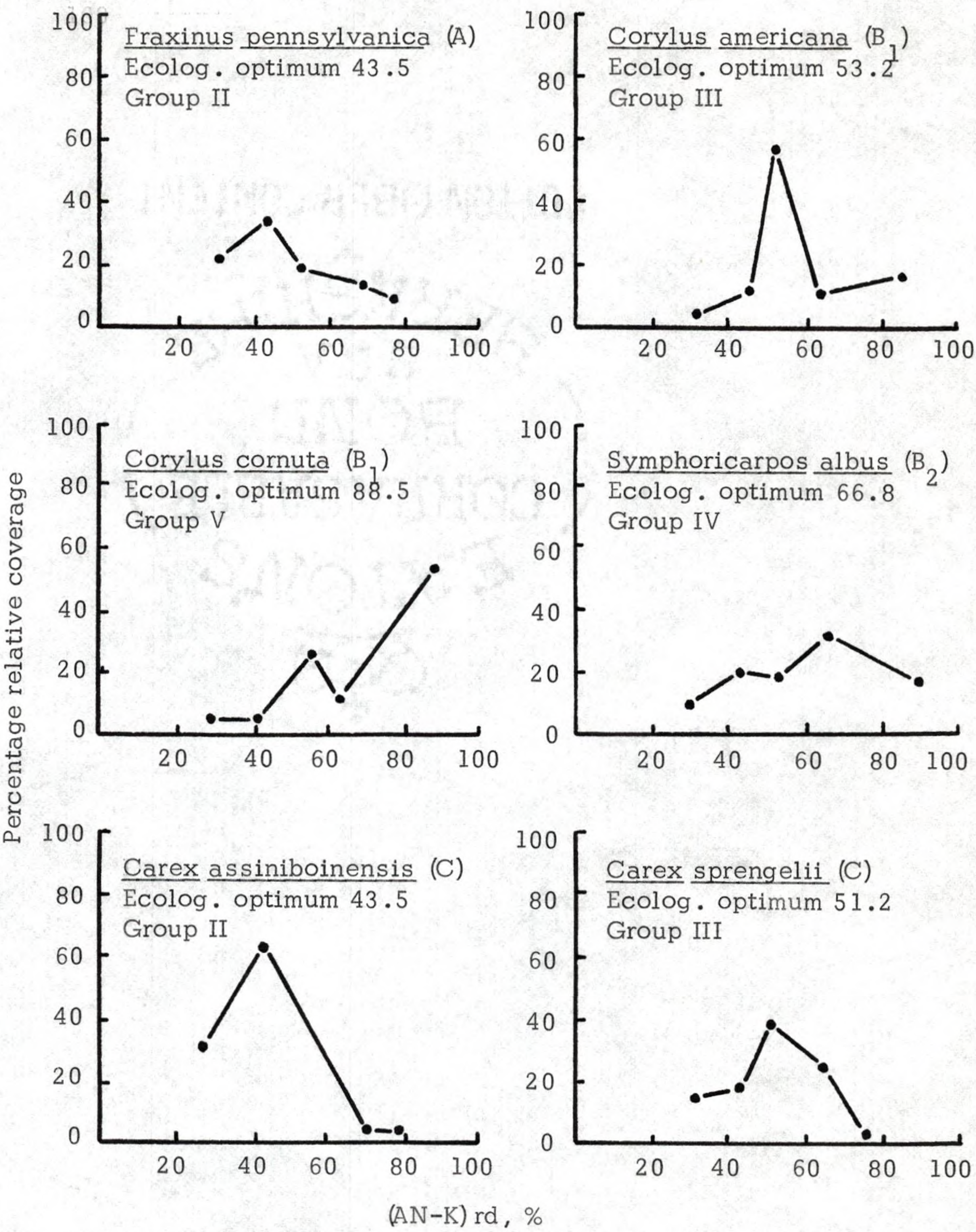


Fig. 24.--Distribution of selected species along the potassium (AN-K)rd gradient.

almost entirely to the floodplain, has a narrow ecological amplitude and low ecological optimum of 29.5. Prunus virginiana, restricted to the slopes, has a wide amplitude along this gradient and has a higher ecological optimum of 49.5.

Distribution of Community Types Along the Gradient

The six environmental variables used for illustrating species distribution along environmental gradients were also used to evaluate distribution of community types. This involved two basic assumptions. First, it was reasoned that if these were the six gradients that were selected most frequently by regression analysis for individual species, they should also give distinguishable patterns of community type distribution. Secondly, the six gradients could be used to group stands in a similar pattern to that obtained by stand ordination. In short, the question to be asked is, can the community type be extrapolated from those environmental parameters judged to play an important role in species distribution?

To evaluate the first assumption, plots of the abundance of community types along each gradient (based on index values) were made. Figures 25, 26, 27, 28, 29, and 30 show these distribution patterns. Although community types 1 and 2 do not show a peak at the same points, they closely parallel each other along all gradients. This is consistent with the fact that the vegetation is similar in these two types. When plotted against all gradients, community type 5 (floodplain) has a dis-

Fig. 25.--Frequency of occurrence of community types along the potential solar beam irradiation (PSBI) gradient. Index numbers correspond to groups (I to V) for the gradient.

Fig. 26.--Frequency of occurrence of community types along the elevation gradient.

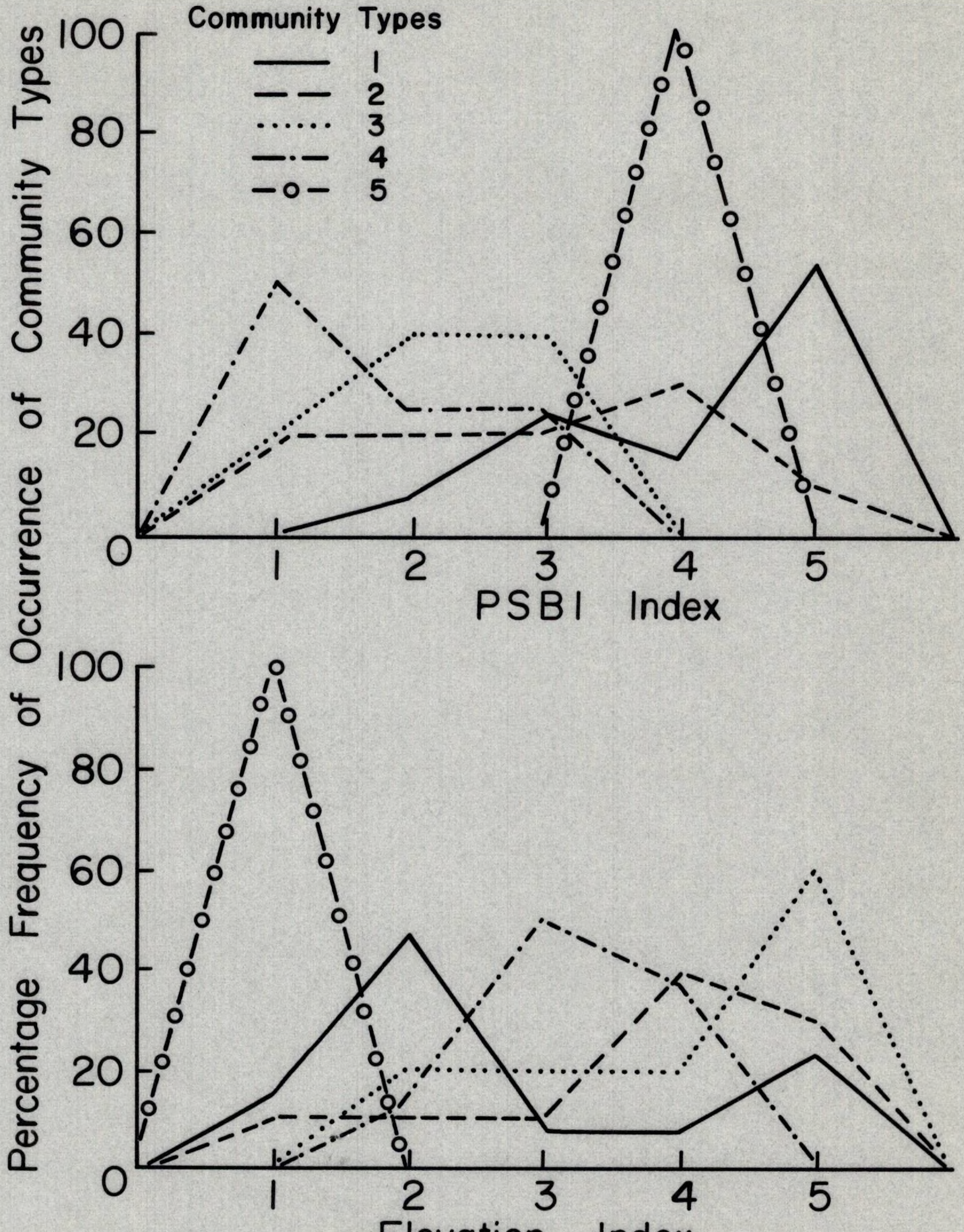

Community Types
1
2
3
4
5
Percentage Frequency of Occurrence of Community Types
100
80
60
40
20
0
1
2
3
4
5
PSBI Index
100
80
60
40
20
0
1
2
3
4
5
Elevation Index

Fig. 27.--Frequency of occurrence of community types along the potassium (AN-K)rd gradient.

Fig. 28.--Frequency of occurrence of community types along the available water capacity (AWC)rd gradient.

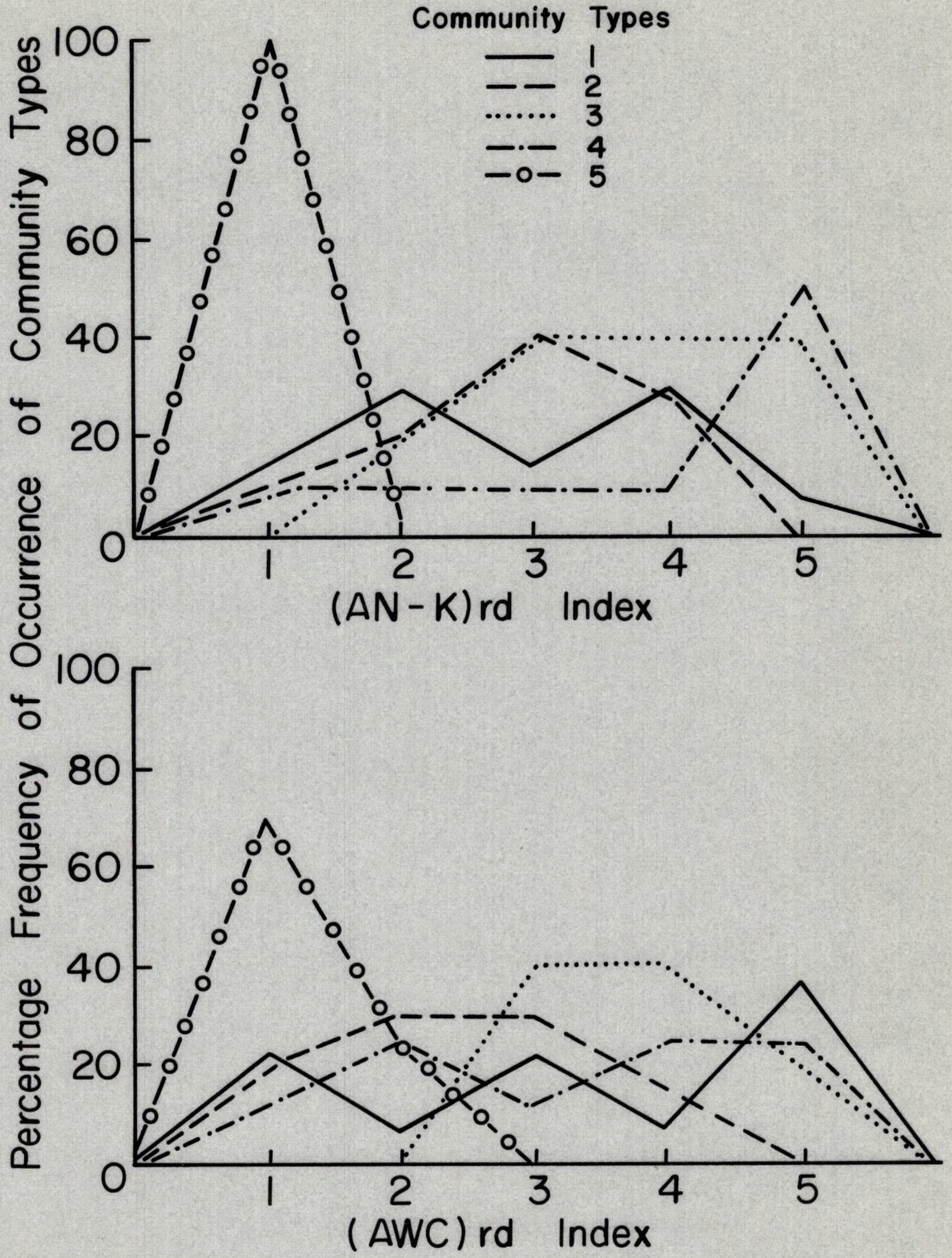
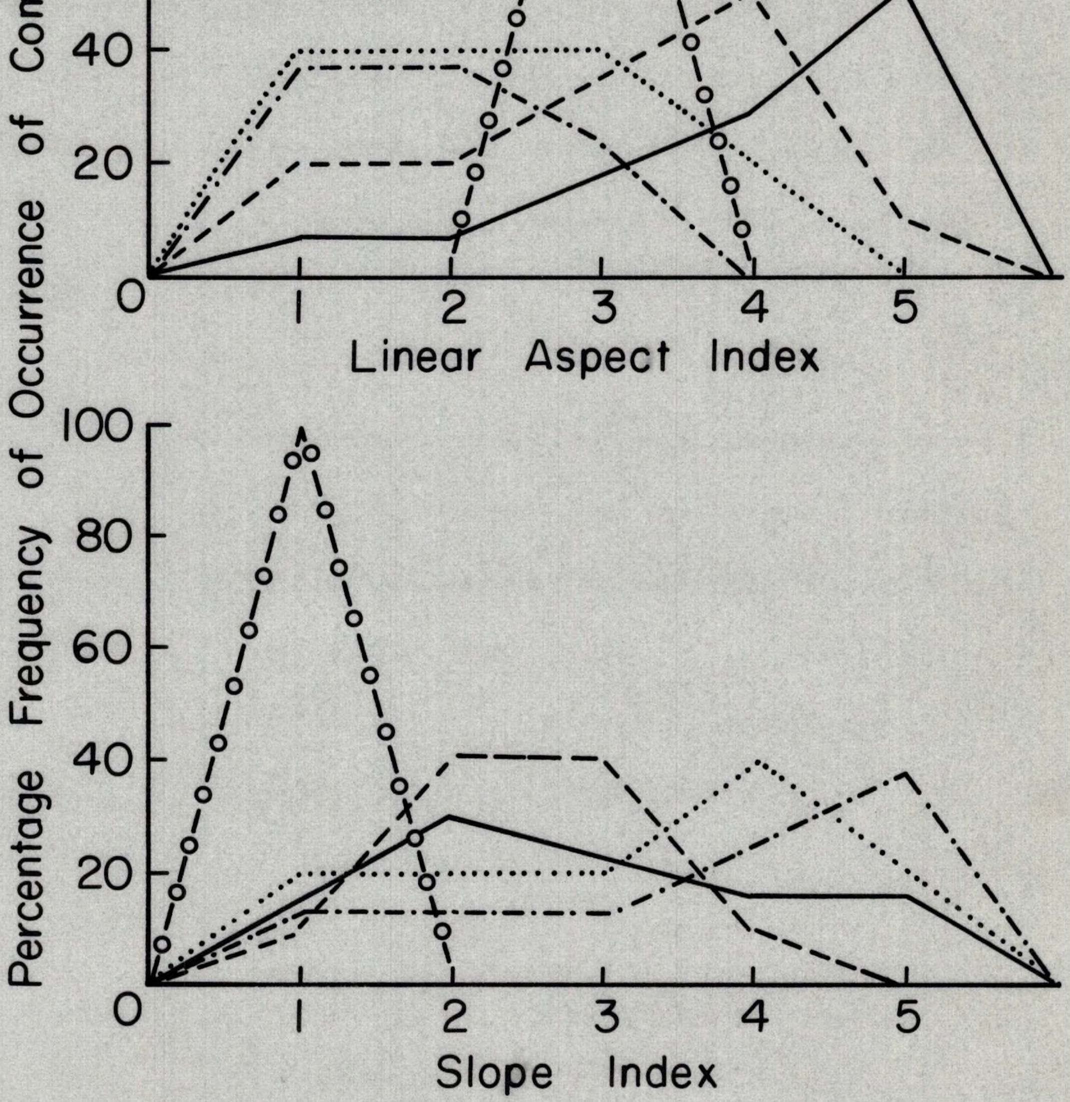

Community Types
1
2
3
4
5
Percentage Frequency of Occurrence of Community Types
0
20
40
60
80
100
1
2
3
4
5
(AN-K)rd Index
0
20
40
60
80
100
1
2
3
4
5
(AWC) rd Index

Fig. 29.--Frequency of occurrence of community types along the linear aspect gradient.

Fig. 30.--Frequency of occurrence of community types along the slope gradient.

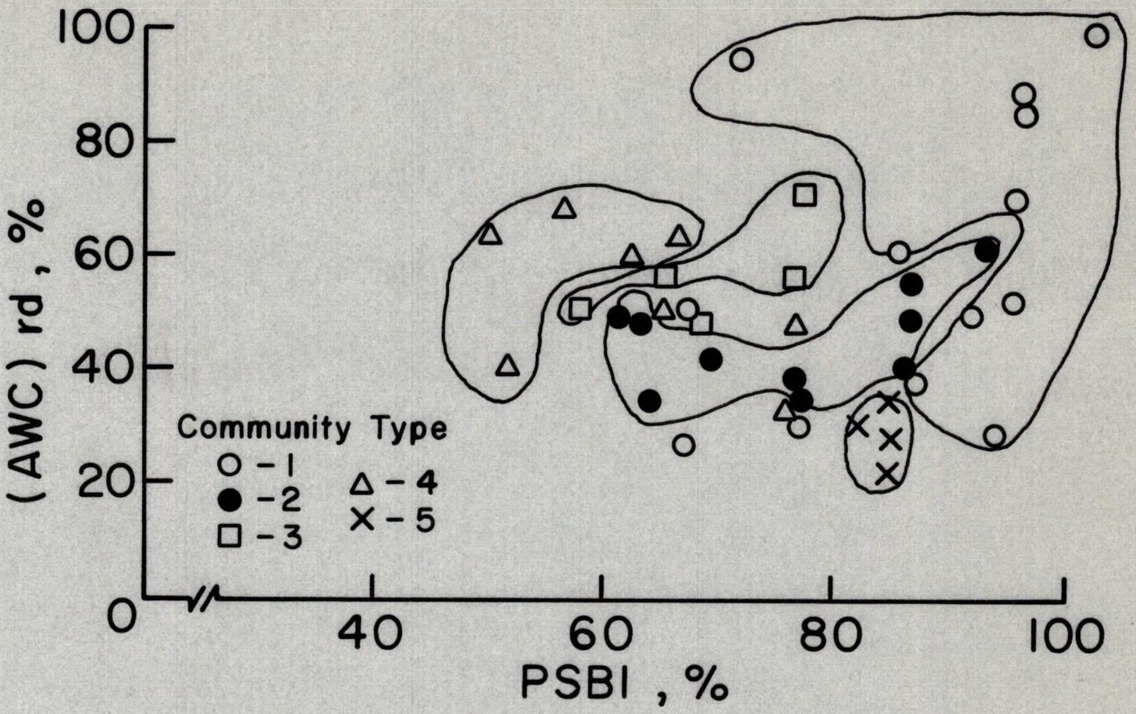

Percentage Frequency of Occurrence of Community Types
Community Types
1
2
3
4
5
100
80
60
40
20
0
1
2
3
4
5
Linear Aspect Index
100
80
60
40
20
0
1
2
3
4
5
Slope Index

distinctive unimodal distribution that sets it apart from all other types. This is a reflection of the contrast in environmental characteristics and vegetation composition between the floodplain and the slopes. While not as pronounced as that of type 5, the distribution pattern for community types 3 and 4 clearly separates each of these two types from all others, particularly along the potential solar beam irradiation, elevation, and available water capacity gradients. Similar to types 1 and 2, these two tend to parallel one another along several gradients. Out of the six gradients, two of them, potential solar beam irradiation and elevation, show distributions which more than the others, clearly distinguish the community types from one another.

To evaluate the second assumption, bivariate plots of all possible combinations for the six selected environmental gradients were made. From these, several bivariate combinations were selected (Figures 31, 32, 33, and 34), which showed patterns of community type distribution resembling those obtained by stand ordination. All but one of these combinations selected contains the potential solar beam irradiation gradient. The exception involves the bivariate combination of elevation and linear aspect. This combination (Figure 33) does not clearly distinguish community type 1 from the others. The other four types separate from each other. The pattern that emerges from these four indicates that stands of the same community type found at higher elevations on more north-facing slopes are restricted to lower elevations on more south-facing slopes.

Fig. 31.--Position of plots in a bivariate combination of available water capacity (AWC)rd and potential solar beam irradiation (PSBI) gradients.

Fig. 32.--Position of plots in a bivariate combination of elevation and potential solar beam irradiation (PSBI) gradients.


(AWC) rd, %
100
80
60
40
20
0
40
60
80
100
PSBI, %
Community Type
○ - 1
● - 2
□ - 3
△ - 4
× - 5

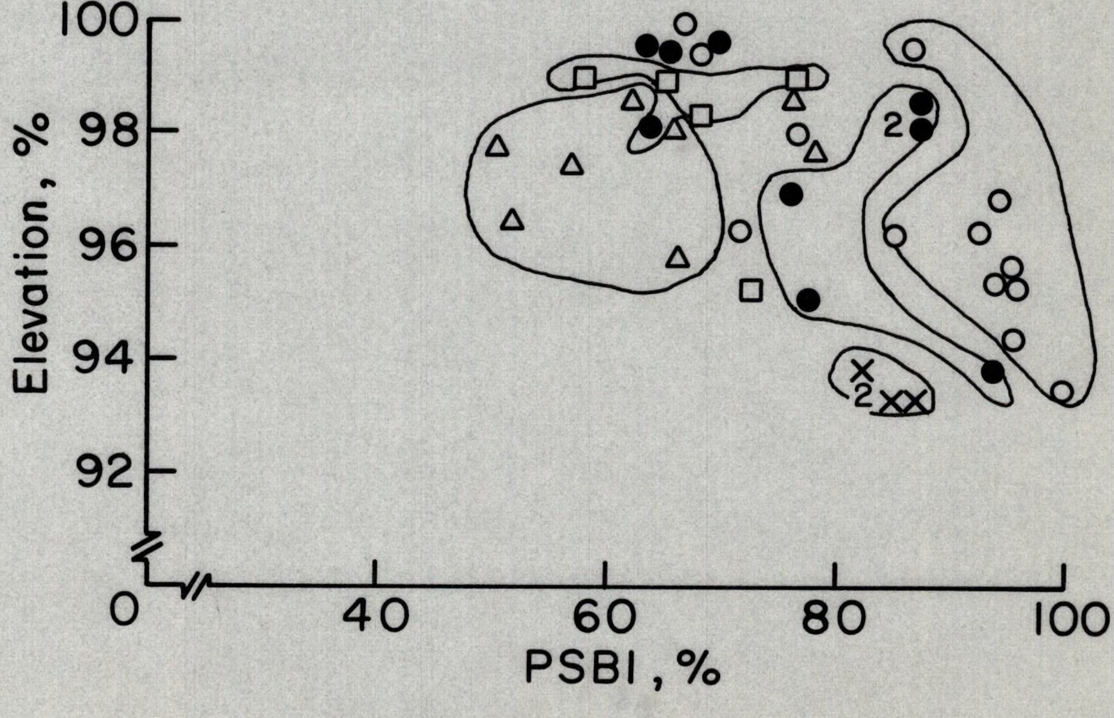
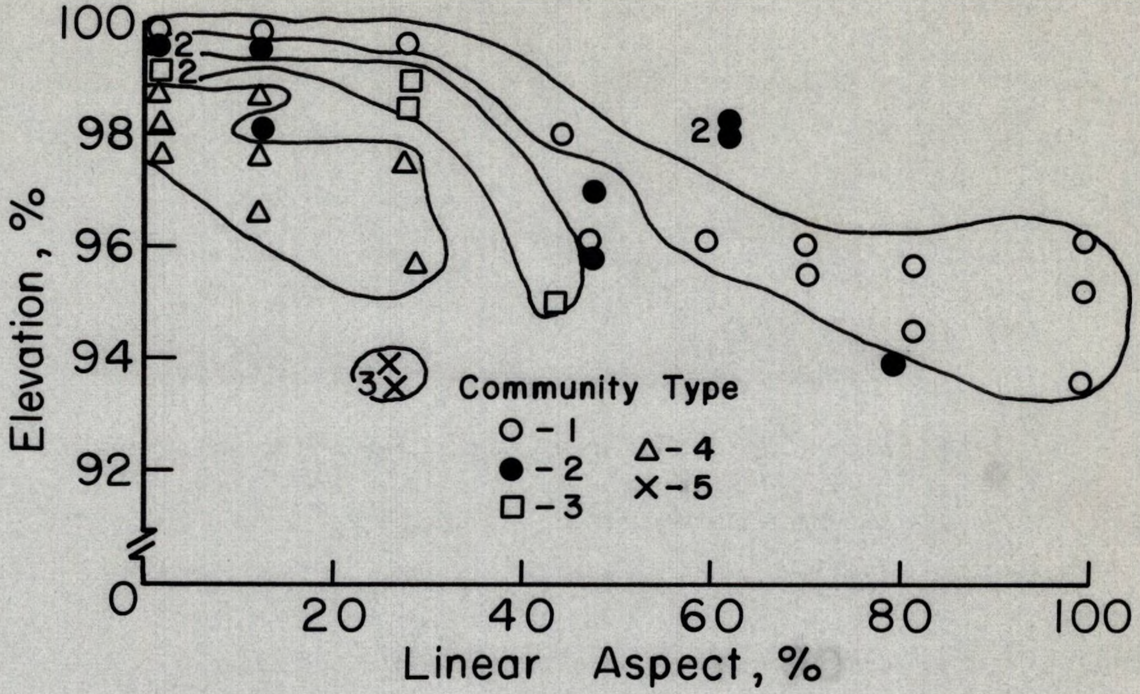
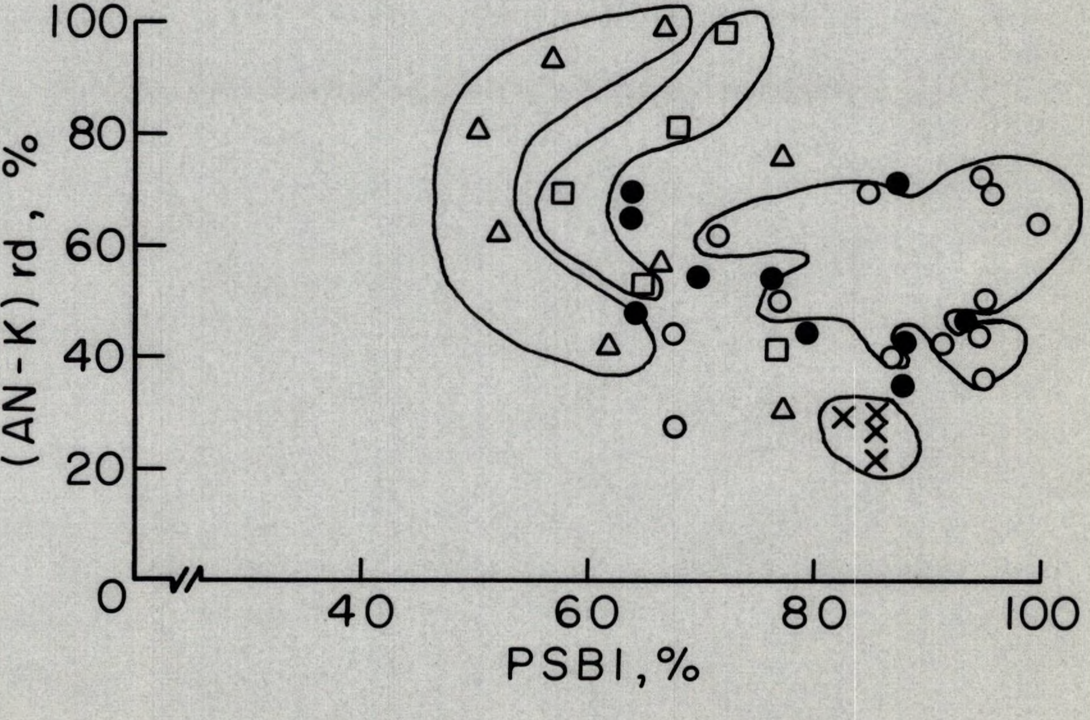

Elevation, %
100
98
96
94
92
0
40
60
80
100
PSBI, %
2
2

Fig. 33.--Position of plots in a bivariate combination of elevation and linear aspect gradients.

Fig. 34.--Position of plots in a bivariate combination of potassium (AN-K)rd and potential solar beam irradiation (PSBI) gradients.


Elevation, %
100
98
96
94
92
0
20
40
60
80
100
Linear Aspect, %
2
2
2
3
Community Type
○ - 1
● - 2
□ - 3
△ - 4
× - 5


(AN-K) rd, %
100
80
60
40
20
0
40
60
80
100
PSBI, %

Potential solar beam irradiation alone stands out as the most effective gradient in grouping stands into community types that best approximate those obtained by ordination. Among the bivariate combinations including potential solar beam irradiation, those with available water capacity, potassium, and elevation are most effective in grouping stands in patterns similar to those obtained by ordination.

The position of the community types relative to each other as obtained by means of these bivariate combinations is similar to those obtained by ordination procedures. In both methods, community types 1 and 4 are separated by types 2 and 3. Similar to groupings by ordination, the bivariate combinations produced tightly clustered groupings of community type 5, clearly set apart from the other types. It must however be pointed out, that none of the first four community types is discrete. Abrupt shifts in types of communities are lacking; there is a gradual blending of one type into another with poorly defined boundaries.

RAINFALL AND LITTER COLLECTIONS

In May, 1971, three plots were selected for a detailed study on nutrient input by litterfall, throughfall, and stemflow. These plots were selected because each represented dominance by one of the three major tree species with the highest importance values. These plots, referred to hereafter by their plot numbers 1, 14, and 23, are dominated by bur oak, green ash, and American basswood, respectively.

On May 18, 1971, four 1-m^2 litter traps (Figure 35) were placed, one in each subplot, in each of the three plots. The litter traps were constructed of 1-mm nylon mesh and suspended from wooden frames set 20 to 25 cm above the ground. Weights were placed in the bottom of each trap to prevent loss of litter by wind action. Litter was first collected from these traps on June 15 and on the 15th of each month thereafter through October. Material from each litter trap was divided into woody (bark, twigs, and branches) and nonwoody (leaves, floral parts, and fruits) portions and each stored in separate paper bags.

Throughfall (rain water falling through the canopy) was collected under one tree selected to represent the dominant species in each of the three stands. Collecting vessels consisted of a Forester rain gauge and two plastic containers placed at random under the canopy of each of the three trees. The openings of the collecting vessels were 25 cm above

Fig. 35.--Litter traps under Tilia americana (plot 23).

ground surface. Gross rain was collected in an identical set of collecting vessels placed in an open prairie site (plot 00) at a distance of about 40 m from the closest edge of the forest. All collecting vessels were covered with 1-mm nylon mesh to prevent collection of particles greater than the mesh size. As the vessels were left out between periods of rainfall, dryfall (dust) was included in all collections. Nutrient input is based on wetfall plus dryfall, a more realistic approach in a region known for considerable wind erosion.

Stemflow was collected by means of polyurethane foam girdles (Likens and Eaton, 1970) installed May 27, 1971, around the trunks of the same trees used for throughfall collection (Figure 36.). The polyurethane foam is sold for use in insulation of buildings. The foam works best when applied at a temperature of about 75° F. In this study the foam for the girdle on the bur oak (plot 1) was applied when the air temperature was considerably cooler and as a result didn't expand properly, causing some leakage down the furrows of the bark. The other two, applied when the air temperature was about 70° F, expanded well and showed little leakage.

The girdles were purposely tilted when installed so that water would drain to one side. Water was channeled from the girdle to a 2-liter collecting bottle at ground level by means of a funnel covered with 1-mm mesh and tygon tubing. All collecting vessels were emptied after each rainfall, but never more than once in a calendar day, from the May 27 installation through October 15. The amount of water in the rain

Fig. 36.--Polyurethane foam collecting girdle on the trunk of _Quercus macrocarpa_ (plot 1).

gauges was read directly on a measuring guage and the volume of water in the plastic vessels measured with a 100-ml graduated cylinder. Each plastic vessel was calibrated empirically so that the volume of water could be converted directly into centimeters of rainfall. When larger amounts of water were collected, phosphorus and sulfate were determined immediately after collection and the remaining water samples were frozen.

The diameter of the long and short axis of the canopy of each tree used for stemflow study was determined and used to calculate the area of the canopy. Following the suggestion of Peek (1970) that the natural shape of the canopy is more like an ellipse than a circle, the following formula was used:

$$\text{area} = (\text{pi}/4)d^1d^2$$

where d^1 and d^2 equal the diameter of the long and short axis. Determination of the area of the tree canopy was necessary to calculate interception of rainfall and total input of nutrients from throughfall and stemflow on a per unit area basis.

Analysis of rain water for sulfate and total phosphate was done immediately after collection according to procedures of the Hach Chemical Company, Ames, Iowa. Rain water samples which had been frozen were thawed and analyzed for calcium, magnesium, potassium, and sodium levels by atomic absorption spectrophotometry. Electrical conductivity and pH were measured on the same apparatus previously described for soil analysis.

The amount of gross rainfall and throughfall obtained in cubic centimeters and the concentration of the chemical elements calcium, magnesium, potassium, sodium, phosphorus and sulfate in parts per million were used to calculate chemical element input in grams per square meter. The stemflow values were equated with gross rainfall and throughfall on a canopy area basis. The input of chemical elements was first determined as grams per canopy area. Approximated canopy areas in square meters were used to adjust these values to nutrient input in grams per square meter. Because there was insufficient water to measure phosphorus and sulfate for all rainfalls, these values are not comparable to the other rainfall data. Therefore, these nutrient values were adjusted proportionately to approximate levels present in the same amount of rainfall or stemflow from which the cations were measured.

Samples collected from litter traps were oven-dried at 80° C for 24 hours and ground into a fine powder with a Waring blender. Before grinding, those litter samples that contained seeds and woody material were first macerated with a mortar and pestle. All material was ground to pass through a 1-mm sieve. Ground samples were stored in glass vials with poly-seal tops.

A dry ashing procedure, modified from Perkin-Elmer, (1971) and Wali, et al. (1972), was employed to determine nutrient levels in the ground plant material. Samples weighing 1.00 ± 0.05 g were placed in porcelain crucibles and ashed in a muffle furnace at 475-500° C for 2 to 4 hours. The weights of the cooled, ashed samples were used to calculate percentage ash content. The ash was dissolved in 10 ml of warm 5 normal HCl and mixed with a glass stirring rod. This solution was placed in a 50 ml volumetric flask and brought to volume with double distilled water. The solution was then filtered through Whatman #3 filter paper. The filtrate was used to determine the major cations, calcium, magnesium, potassium, and sodium, and the trace elements, strontium, manganese, zinc, iron, copper and aluminum by atomic absorption spectrophotometry. Phosphorous was determined from the same filtrate by the vanadomolybdophosphoric yellow color method (Jackson, 1958).

The weights of the woody and nonwoody litter collected from each litter trap and their respective chemical element nutrient levels were used to calculate nutrient input in grams per meter square. Values from the four litter traps in each plot were calculated separately, averaged, and summed to give seasonal totals. In some cases there was insufficient woody litter to run four separate analyses. Therefore, the samples from the four traps were pooled.

RESULTS: RAINFALL AND LITTER PRODUCTION

Input Through Rainfall

From May 18 to October 15, 1971, a total of 30 individual rainfalls were recorded. Seasonal totals of gross rainfall, throughfall, and stemflow and their combined totals are given in Table 17. Total gross rainfall for this period as measured in plot 00 on the open prairie (used as a control site) was 351.7 mm. The range for rainfall (Table 18) was from 0.2 to 5.89 cm. The amounts of throughfall for individual rainfalls collected under canopies of three tree species are shown in Table 18 and amount of stemflow in Table 19.

TABLE 17

TOTAL SEASONAL NET RAINFALL UNDER *QUERCUS*, *FRAXINUS*, AND *TILIA* TREES AND PERCENTAGE INTERCEPTION OF GROSS RAINFALL BY THESE SPECIES

Plot	Net rainfall in mm			Percentage interception
	Throughfall+	Stemflow[a]=	Total	
00 (gross rainfall)			351.7	
1 (*Quercus*)	311.7	0.05	311.7	11.4
14 (*Fraxinus*)	308.1	0.37	308.4	12.3
23 (*Tilia*)	248.4	0.32	248.7	29.3

[a] expressed as equivalent rainfall depth

TABLE 18

AMOUNT AND CHEMICAL PROPERTIES OF EACH RAINFALL COLLECTED IN A CONTROL PRAIRIE PLOT (P) AND UNDER QUERCUS (Q), FRAXINUS (F), AND TILIA (T) CANOPIES, 1971

Collection date	Sample type	Mean rainfall (cm)	Mean pH	Mean specific conductivity (micromhos/cm)	ppm, means					
					Ca	Mg	K	Na	P	SO_4
5-18	P	0.51	5.5	56.9	3.04	0.61	1.33	9.55	--	--
5-18	Q	0.43	5.5	84.5	2.24	0.85	4.08	13.75	--	--
5-18	F	0.28	7.0	155.2	13.80	2.85	7.55	14.85	--	--
5-18	T	0.23	6.9	6.9	0.24	0.10	0.16	0.20	--	--
5-24	P	0.99	5.9	25.9	0.26	0.17	0.69	6.05	--	--
5-24	Q	0.79	6.4	48.3	2.12	0.55	3.16	8.65	--	--
5-24	F	1.04	6.6	75.6	5.72	1.62	8.65	11.10	--	--
5-24	T	0.84	6.4	75.9	6.28	1.77	7.99	1.02	--	--
6- 5	P	0.79	6.0	63.8	2.89	0.84	5.28	6.05	--	--
6- 5	Q	0.66	6.1	96.5	2.92	1.39	14.55	9.40	--	--
6- 5	F	0.58	6.2	77.6	2.86	1.32	9.49	9.00	--	--
6- 5	T	0.71	6.6	301.7	8.30	0.64	22.45	1.62	--	--
6-10	P	2.87	5.6	15.5	0.56	0.10	0.59	5.95	0.06	8.0
6-10	Q	2.03	5.8	31.0	1.44	0.50	4.60	8.75	0.36	6.0
6-10	F	2.49	6.1	36.2	1.98	0.68	5.31	4.60	0.36	6.5
6-10	T	2.08	6.8	70.7	2.38	1.51	10.73	6.65	0.87	6.0
6-11	P	0.33	8.1	155.2	15.40	4.45	1.88	10.20	--	--
6-11	Q	0.13	7.0	43.1	3.26	1.24	4.08	2.05	--	--
6-11	F	0.15	8.3	172.4	16.10	5.40	4.08	5.70	--	--

TABLE 18--Continued

Collection date	Sample type	Mean rainfall (cm)	Mean pH	Mean specific conductivity (micromhos/cm)	ppm, means					
					Ca	Mg	K	Na	P	SO_4
6-11	T	0.09	7.2	58.6	4.18	1.47	6.58	1.09	--	--
6-15	P	0.38	6.3	37.9	2.36	0.64	0.85	5.55	--	--
6-15	Q	0.23	6.1	65.5	3.24	1.34	9.45	7.40	--	--
6-15	F	0.23	6.8	103.4	5.78	2.65	10.25	8.05	--	--
6-15	T	0.18	7.1	293.1	9.69	7.60	43.45	11.50	--	--
6-16	P	1.73	6.4	10.3	0.60	0.20	1.09	6.50	0.25	9.0
6-16	Q	1.70	6.5	27.6	1.34	0.40	4.24	7.10	0.26	6.0
6-16	F	1.57	6.3	31.0	2.17	0.55	2.33	5.45	0.57	6.5
6-16	T	1.37	6.7	69.0	4.48	1.76	7.93	5.75	0.84	6.5
6-19	P	0.22	6.9	56.9	3.40	1.13	1.22	5.70	--	--
6-19	Q	0.18	6.6	60.3	3.47	1.38	7.04	7.30	--	--
6-19	F	0.15	6.6	79.3	3.99	1.56	6.29	9.50	--	--
6-19	T	0.13	7.0	224.1	14.30	7.05	32.75	3.15	--	--
6-21	P	0.97	5.7	15.5	0.89	0.18	0.45	3.65	--	--
6-21	Q	0.81	5.8	20.7	0.94	0.29	2.91	8.00	--	--
6-21	F	0.66	6.3	25.9	1.48	0.43	2.77	5.45	--	--
6-21	T	0.58	7.0	62.1	2.96	1.45	8.79	9.05	--	--
6-29	P	0.97	5.6	27.6	1.01	0.25	0.64	4.65	--	--
6-29	Q	0.91	5.7	36.2	1.71	0.62	4.95	5.60	--	--
6-29	F	0.81	6.6	79.3	4.45	1.93	10.30	6.65	--	--
6-29	T	0.89	5.8	43.1	2.43	0.74	3.91	6.65	--	--

TABLE 18--Continued

Collection date	Sample type	Mean rainfall (cm)	Mean pH	Mean specific conductivity (micromhos/cm)	ppm, means					
					Ca	Mg	K	Na	P	SO_4
7- 3	P	0.28	6.8	50.0	4.61	0.71	1.88	6.75	--	--
7- 3	Q	0.51	6.6	51.7	2.12	0.76	7.23	10.30	--	--
7- 3	F	0.15	7.0	81.0	5.09	1.93	6.32	7.25	--	--
7- 3	T	0.10	7.4	189.7	14.20	5.70	15.20	3.80	--	--
7- 7	P	1.09	6.2	20.7	0.79	0.19	0.51	7.75	0.16	6.5
7- 7	Q	0.91	6.0	32.8	1.56	0.48	4.87	6.35	0.14	8.0
7- 7	F	0.94	6.4	31.0	2.42	0.69	2.52	5.70	0.14	7.0
7- 7	T	0.79	6.8	67.2	4.16	1.89	7.89	8.55	0.25	8.5
7-12	P	2.06	6.1	12.1	0.31	0.07	0.39	6.60	0.26	8.5
7-12	Q	2.01	6.0	25.9	0.99	0.32	3.68	4.40	0.09	8.0
7-12	F	2.03	6.2	24.1	1.72	0.53	1.88	3.80	0.21	8.0
7-12	T	1.27	6.6	44.8	2.49	1.08	5.36	7.55	0.26	7.0
7-14	P	0.71	6.4	12.1	0.47	0.11	0.44	4.45	0.11	6.0
7-14	Q	0.71	6.2	19.0	0.76	0.21	2.26	6.70	0.09	6.5
7-14	F	0.58	6.5	25.9	1.55	0.47	2.08	5.60	0.32	6.5
7-14	T	0.53	6.9	43.1	2.25	0.79	5.23	6.50	0.28	6.0
7-18	P	5.89	5.4	5.2	0.17	0.03	0.15	2.50	0.25	6.5
7-18	Q	5.87	6.3	10.3	0.48	0.12	1.35	2.25	0.26	4.5
7-18	F	5.18	6.3	10.3	0.37	0.03	0.74	6.10	0.21	7.0
7-18	T	4.09	6.7	22.4	1.29	0.41	2.18	5.70	0.21	7.0

TABLE 18--Continued

Collection date	Sample type	Mean rainfall (cm)	Mean pH	Mean specific conductivity (micromhos/cm)	ppm, means					
					Ca	Mg	K	Na	P	SO_4
7-20	P	0.99	5.7	8.6	0.10	0.02	0.25	5.25	--	--
7-20	Q	0.99	6.3	12.1	0.39	0.09	1.59	5.60	--	--
7-20	F	0.91	6.4	15.5	0.33	0.07	1.20	6.60	--	--
7-20	T	0.69	7.0	34.5	1.26	0.41	4.02	7.20	--	--
7-24	P	0.84	6.4	15.5	0.30	0.11	0.51	5.20	0.21	8.0
7-24	Q	0.81	6.4	17.2	0.62	0.16	2.06	6.50	0.07	8.0
7-24	F	0.84	6.5	20.7	0.98	0.35	1.57	6.15	0.23	7.0
7-24	T	0.61	6.7	55.2	2.39	0.88	6.85	10.10	1.62	7.0
7-27	P	0.51	6.6	20.7	0.74	0.24	0.52	5.45	--	--
7-27	Q	0.33	6.6	20.7	0.93	0.38	3.51	6.90	--	--
7-27	F	0.33	6.7	29.3	1.32	0.38	2.74	5.90	--	--
7-27	T	0.23	7.0	69.0	2.91	1.50	10.19	8.35	--	--
7-29	P	0.25	6.3	6.9	0.10	0.06	0.46	8.00	--	--
7-29	Q	0.23	6.4	19.0	0.31	0.13	2.64	8.40	--	--
7-29	F	0.18	6.8	22.4	0.46	0.09	2.35	5.50	--	--
7-29	T	0.20	7.2	53.4	1.22	0.38	8.07	8.05	--	--
8-13	P	3.40	6.3	19.0	0.63	0.21	0.54	5.50	0.14	5.0
8-13	Q	3.00	6.4	27.6	1.54	0.48	3.88	9.00	0.12	5.0
8-13	F	3.25	6.5	31.0	2.18	0.66	2.34	7.30	0.26	4.5
8-13	T	2.57	6.5	51.7	2.07	0.82	6.82	10.45	0.50	3.5
8-17	P	0.53	6.7	24.1	0.97	0.13	0.97	7.20	--	--
8-17	Q	0.43	6.3	46.6	2.12	0.66	7.26	8.65	--	--

TABLE 18--Continued

Collection date	Sample type	Mean rainfall (cm)	Mean pH	Mean specific conductivity (micromhos/cm)	ppm, means					
					Ca	Mg	K	Na	P	SO_4
8-17	F	0.46	6.7	37.9	2.04	0.68	3.21	5.45	--	--
8-17	T	0.28	7.4	65.5	2.86	0.42	9.13	7.75	--	--
8-24	P	0.74	6.8	32.8	1.43	0.35	0.97	1.55	--	--
8-24	Q	0.69	6.1	55.2	2.54	0.76	9.33	9.00	--	--
8-24	F	0.74	6.4	46.6	2.93	0.76	2.91	9.05	--	--
8-24	T	0.49	7.1	74.1	3.60	1.36	10.42	8.75	--	--
8-29	P	0.71	6.5	37.9	1.34	0.35	1.17	8.10	--	--
8-29	Q	0.53	5.8	51.7	2.06	0.69	6.01	7.55	--	--
8-29	F	0.69	6.3	27.6	2.71	0.77	3.75	8.60	--	--
8-29	T	0.48	6.1	103.4	4.19	1.42	12.30	9.25	--	--
8-31	P	0.20	6.3	67.2	1.56	0.57	1.04	4.25	--	--
8-31	Q	0.14	7.1	120.7	4.17	1.72	9.89	6.30	--	--
8-31	F	0.11	6.3	81.0	2.89	1.13	8.52	8.35	--	--
8-31	T	0.15	6.3	163.8	6.93	2.90	15.15	8.50	--	--
9- 3	P	0.33	6.6	32.8	0.91	0.30	0.66	4.45	--	--
9- 3	Q	0.28	6.4	103.4	2.71	1.15	10.82	9.20		
9- 3	F	0.28	6.5	69.0	1.85	0.73	8.03	8.95	--	--
9- 3	T	0.20	7.4	172.4	4.24	1.90	19.30	8.45	--	--
9- 5	P	2.01	6.2	12.1	0.38	0.13	0.26	8.30	0.26	2.0
9- 5	Q	1.98	6.2	17.2	0.90	0.37	5.01	5.75	0.17	2.0
9- 5	F	1.98	6.2	46.6	1.40	0.53	2.97	8.10	0.78	4.5
9- 5	T	1.55	6.7	55.2	1.87	0.79	6.91	7.95	1.10	3.5

TABLE 18--Continued

Collection date	Sample type	Mean rainfall (cm)	Mean pH	Mean specific conductivity (micromhos/cm)	ppm, means					
					Ca	Mg	K	Na	P	SO_4
9-16	P	0.25	7.0	36.2	1.83	0.53	1.04	6.75	--	--
9-16	Q	0.20	6.5	70.7	2.43	1.19	9.67	8.20	--	--
9-16	F	0.13	6.6	112.1	5.37	1.76	12.05	9.95	--	--
9-16	T	0.13	7.5	198.3	5.76	1.83	16.85	10.30	--	--
9-27	P	1.32	6.1	32.8	0.52	0.26	0.51	7.75	0.07	9.0
9-27	Q	0.99	5.5	53.4	2.28	0.85	5.82	7.25	0.81	9.0
9-27	F	1.12	5.8	84.5	2.06	1.04	11.80	7.70	3.02	7.0
9-27	T	0.79	6.5	129.3	5.78	2.04	15.55	7.70	3.16	8.5
9-30	P	0.48	5.1	31.0	1.07	0.31	0.39	8.10	--	--
9-30	Q	0.38	6.0	51.7	2.09	0.79	5.92	8.75	--	--
9-30	F	0.38	5.6	48.3	1.53	0.63	4.92	7.40	--	--
9-30	T	0.38	6.4	103.4	4.15	1.64	14.20	4.65	--	--
10- 3	P	2.82	5.5	10.3	0.14	0.02	0.26	7.25	0.06	5.0
10- 3	Q	2.67	6.1	29.3	0.61	0.25	4.57	7.25	0.06	5.0
10- 3	F	2.57	6.3	24.1	1.14	0.22	1.97	7.05	0.44	7.0
10- 3	T	2.21	6.4	25.9	0.72	0.09	3.55	6.90	0.76	5.0
means	P	1.17	6.2	31.8	1.61	0.44	0.90	6.17	0.16	6.7
means	Q	1.04	6.2	45.0	1.79	0.67	5.54	7.42	0.27	6.2
means	F	1.03	6.5	56.8	3.26	1.08	5.03	7.36	0.59	6.4
means	T	0.83	6.8	97.6	4.29	1.75	10.33	6.77	0.86	6.2

TABLE 19

AMOUNT AND CHEMICAL PROPERTIES OF STEMFLOW FOR EACH RAINFALL COLLECTED FROM THE TRUNKS OF *QUERCUS* (Q), *FRAXINUS* (F), AND *TILIA* (T), 1971

Collection date	Sample type	Stemflow (ml)	pH	Specific conductivity (micromhos/cm)	ppm					
					Ca	Mg	K	Na	P	SO_4
5-24	Q	12	5.7	362.1	34.40	10.10	37.65	4.20	--	--
6- 5	Q	11	7.3	275.9	14.50	6.15	45.50	6.50	--	--
6- 5	F	242	6.6	155.2	15.70	3.95	23.75	8.20	--	--
6- 5	T	471	6.5	275.9	30.45	6.10	34.75	7.50	--	--
6-10	Q	68	6.8	310.3	24.15	6.60	26.65	7.85	--	--
6-10	F	1601	6.6	112.1	13.80	3.30	20.25	9.30	1.45	2.5
6-10	T	231	6.5	396.6	38.90	10.10	41.40	2.20	--	--
6-16	Q	78	7.2	137.9	13.15	3.10	16.05	5.95	2.50	9.0
6-16	F	718	6.8	84.5	6.32	1.66	13.40	5.65	2.14	4.5
6-16	T	301	7.2	137.9	13.15	3.10	16.05	5.95	2.51	9.0
6-21	Q	9	8.0	241.4	19.35	7.25	8.40	6.15	--	--
6-21	F	103	7.1	93.1	5.48	1.53	13.10	8.00	--	--
6-21	T	85	7.3	163.8	14.25	4.75	14.40	6.40	--	--
6-29	Q	24	6.4	82.8	6.81	2.24	14.50	2.25	--	--
6-29	F	22	6.5	129.3	8.87	2.85	10.40	3.20	--	--
6-29	T	429	6.2	41.4	10.34	2.80	16.95	6.80	--	--
7- 7	Q	12	6.0	72.4	6.42	2.02	8.77	2.30	--	--
7- 7	F	433	6.9	112.1	9.61	2.43	18.40	8.40	2.87	9.0
7- 7	T	14	7.2	112.1	9.17	2.85	9.90	4.10	--	--

TABLE 19.--Continued

Collection date	Sample type	Stemflow (ml)	pH	Specific conductivity (micromhos/cm)	ppm					
					Ca	Mg	K	Na	P	SO_4
7-12	Q	45	6.6	70.7	5.05	1.37	11.40	5.95	--	--
7-12	F	730	6.8	70.7	4.39	1.32	13.55	4.20	1.57	7.0
7-12	T	1310	7.0	112.1	11.75	2.50	16.30	4.35	2.66	4.5
7-14	Q	14	6.9	55.2	4.06	1.28	10.34	1.40	--	--
7-14	F	246	7.0	37.9	7.93	2.25	17.20	8.90	2.34	6.0
7-14	T	9	7.1	67.2	9.98	2.19	7.93	2.55	--	--
7-18	Q	430	6.9	106.9	14.51	2.95	36.35	6.90	0.32	6.0
7-18	F	1405	6.8	24.1	3.05	0.74	7.95	7.75	1.07	6.0
7-18	T	2053	7.3	67.2	4.53	1.12	11.35	10.60	1.67	7.0
7-24	Q	14	7.1	51.7	1.97	0.27	9.24	1.20	--	--
7-24	F	183	7.1	103.4	7.90	2.29	15.60	7.45	1.86	8.5
7-24	T	62	7.0	53.4	4.42	0.98	6.54	7.30	--	--
8-13	Q	265	6.9	137.9	8.65	1.70	28.20	12.70	0.48	9.5
8-13	F	1043	7.0	89.7	5.34	1.61	14.15	10.60	1.76	6.5
8-13	T	1890	7.1	103.4	9.98	2.19	15.90	4.10	1.86	4.5
8-24	Q	12	6.6	79.3	3.43	0.61	9.77	1.55	--	--
8-24	F	221	7.3	327.6	22.60	8.60	19.25	25.45	--	--
8-24	T	15	7.1	112.1	8.61	2.35	13.55	5.50	--	--

TABLE 19.--Continued

Collection date	Sample type	Stemflow (ml)	pH	Specific conductivity (micromhos/cm)	ppm					
					Ca	Mg	K	Na	P	SO_4
8-29	Q	13	6.5	39.7	3.48	0.75	9.23	1.85	--	--
8-29	F	251	6.3	241.4	20.59	6.40	44.05	10.10	--	--
8-29	T	26	6.9	87.9	16.56	3.85	18.35	6.70	--	--
9- 3	F	15	6.4	53.4	5.87	1.91	10.78	6.75	--	--
9- 5	Q	35	6.7	43.1	1.42	0.38	8.63	7.80	--	--
9- 5	F	1984	6.8	75.9	4.72	1.31	12.85	4.51	1.45	5.0
9- 5	T	531	6.4	94.8	8.29	1.91	13.55	9.45	2.41	3.5
9-27	Q	30	6.8	112.1	6.19	1.04	8.35	6.30	--	--
9-27	F	518	6.4	137.9	7.43	1.66	17.85	7.30	3.08	9.7
9-27	T	159	6.3	163.8	16.55	3.60	19.45	7.75	3.08	4.5
9-30	Q	9	6.9	103.4	5.96	1.66	19.30	6.30	--	--
9-30	F	95	6.9	241.4	25.51	6.65	45.35	10.50	--	--
10- 3	Q	91	6.6	50.0	1.65	0.46	10.11	5.70	0.28	3.5
10- 3	F	1029	6.9	120.7	5.32	1.97	23.05	7.85	2.56	6.5
10- 3	T	1993	6.2	94.8	7.76	1.40	12.80	7.00	2.34	5.0
means	Q	65	6.8	131.8	9.23	2.68	18.00	4.83	0.89	7.0
means	F	536	7.0	134.7	11.74	3.52	18.40	8.40	2.13	6.5
means	T	565	6.8	139.8	14.17	3.34	17.34	5.83	2.36	5.4

Stemflow, excluding bur oak where leakage occurred in the collecting girdle, was slightly higher from green ash than basswood. However, stemflow from each of these two contribute only about 0.1% of the total net rainfall associated with each species.

The interception of the rainfall by tree canopies is greatest for basswood (29.3%) followed by green ash (12.3%) and bur oak (11.4%). The dense, closed nature of the basswood, as opposed to the more open nature of bur oak and green ash, may account for this difference. The coarse textured surface of the basswood leaves as opposed to the smooth, waxy surface of the bur oak and green ash leaves may also be a factor.

The results of the chemical analysis of gross rainfall, throughfall, and stemflow for each of the three plots are shown in Tables 18 and 19. Although referred to as gross rainfall and throughfall, these values in actuality include input by dust between periods of rainfall.

The range of pH values in all samples is from a low of 5.5 in the gross rainfall and throughfall collection of plot 1 to a high of 8.6 for stemflow in plot 14. The mean pH values for gross rainfall and throughfall in plot 1 are both 6.2, while mean pH of throughfall is 6.5 for plot 14 and 6.8 for plot 23. The mean pH of the stemflow for plots 1 and 14, 6.8 and 7.0, respectively, is slightly higher than the throughfall in these plots. The mean pH of stemflow in plot 23 (6.8) is the same as the throughfall in the same plot.

The collecting sites as well as the dates of collection showed considerable variation in conductivity values. The low of 5.2 micromhos/

cm was measured in the gross rainfall collected after a heavy rain. The maximum value, 396.6 micromhos/cm, occurred in stemflow collected in plot 23. Gross rainfall had the lowest mean value (31.8 micromhos/cm). Mean values for throughfall are 45.0, 56.8, and 97.6 micromhos/cm for plots 1, 14, and 23, respectively. In all three plots, the stemflow values are higher than those for throughfall. Given in the same order as throughfall, these mean values are 131.8, 134.7, and 139.8, micromhos/cm.

Several noticeable patterns exist in levels of chemical elements among the different types of rainfall. For example, the mean values of calcium, magnesium, potassium, and phosphorus are higher in both stemflow and throughfall in all plots than in gross rainfall. Among the samples collected, only stemflow in plot 1 has mean sulfate levels higher than the gross rainfall. Relative to levels of sodium in the gross rainfall, only stemflow in plots 1 and 23 have lower mean values.

Simple linear correlations between the chemical properties and amounts of gross rainfall (plot 00) stemflow and throughfall plots 1, 14, and 23 are presented in Table 20. With few exceptions, negative correlations exist between the amount of gross rainfall, throughfall, and stemflow collected and their chemical properties. One of these exceptions, the stemflow in plot 1, gives positive correlations in most cases. As mentioned previously in describing the methods for collecting stemflow, some leakage occurred from this tree girdle. As a result, these samples did not undergo the normal dilution effect noted in plots 14 and 23 where

TABLE 20

MEAN AMOUNT OF GROSS RAINFALL, STEMFLOW, AND THROUGHFALL IN PLOTS STUDIED AND CORRELATION COEFFICIENTS BETWEEN THESE VALUES AND THEIR CHEMICAL PROPERTIES

Type of rainfall	Plot	Mean rainfall	Correlation Coefficient					
			pH	Conductivity	Ca	Mg	K	Na
		mm						
Gross	00	11.7	-.436[a]	-.408[a]	-.286	-.276	-.280	-.252
		ml						
Stemflow	1	65.1	.094	.143	.091	-.062	.422	.523[a]
	14	536.2	-.291	-.468[a]	-.482[a]	-.489[a]	-.224	-.205
	23	564.9	-.029	-.250	-.317	-.371	-.137	.312
		mm						
Throughfall	1	10.4	-.143	-.471[b]	-.499[b]	-.495[b]	-.403[a]	-.397[a]
	14	10.3	-.315	-.464[b]	-.340	-.388[a]	-.416[a]	-.280
	23	8.3	-.355	-.400[a]	-.399[a]	-.344	-.330	.064

[a] significant at 0.05 level

[b] significant at 0.01 level

the girdles were more effective in collecting stemflow. The other noteworthy exceptions are the positive correlations between amounts of stemflow and throughfall and sodium in plot 23. Although neither is statistically significant, the correlation coefficient between amount of stemflow and sodium is quite high. Higher negative correlations exist between amount of rainfall and conductivity than between rainfall and pH.

The large number of negative correlations between the amount of rainfall and its chemical elements points out the need to express these in some other manner than as concentrations. Therefore, taking both amount and concentration into consideration, the chemical elements were calculated on a weight per unit area basis. In addition, because of their role in nutrient cycling, the chemical elements are expressed on a rate basis rather than per individual rainfall. Table 21 contains these values expressed as grams per square meter per collecting season for gross rainfall and throughfall and milligrams per square meter per collecting season for stemflow.

Comparison between input of chemical elements by throughfall and stemflow (Table 21) indicates the former contributes considerably more than the latter. There is a larger amount of input of all chemical elements by net rainfall than by gross rainfall except for sodium in plot 23 and sulfate in plots 1, 14, and 23. This coupled with the fact that throughfall values by themselves are also lower in sodium in plot 23 and sulfate in plots 1, 14, and 23 than the gross rainfall, indicates the tree canopy intercepts these elements. This suggests a differential trapping or foliar

TABLE 21

SEASONAL INPUT OF CHEMICAL ELEMENTS BY GROSS RAINFALL IN PLOT 00 AND BY NET RAINFALL (THROUGHFALL AND STEMFLOW) IN PLOTS 1, 14, AND 23

	Chemical elements					
Plot	Ca	Mg	K	Na	P	SO$_4$
			Throughfall, g/m^2			
1	0.3857	0.1331	1.2955	2.0034	0.0844	1.7425
14	0.6090	0.1937	1.0809	2.0633	0.1464	1.9740
23	0.7023	0.2649	1.8693	1.7313	0.1759	1.4638
			Stemflow, mg/m^2			
1	0.503	0.114	1.241	0.356	0.027[a]	0.320[a]
14	2.941	0.821	6.240	2.889	0.687[a]	2.201[a]
23	3.335	0.737	5.039	2.176	0.681[a]	1.704[a]
			Gross and net rainfall (throughfall+stemflow), g/m^2			
00	0.2773	0.0765	0.2222	1.9957	0.0600	2.2658
1	0.3862	0.1332	1.2967	1.0038	0.0844	1.7429
14	0.6119	0.1945	1.0871	2.0662	0.1471	1.9762
23	0.7056	0.2656	1.8653	1.7335	0.1766	1.4655

[a] values adjusted by proportion to equal the same amount of rainfall as for cation values

absorption of sodium by basswood and sulfate by all three species.

Each of the three tree species has a unique system of altering the chemical properties of the gross rainfall. For example, the order of magnitude of chemical elements from largest to smallest in the gross rainfall is sulfate, sodium, calcium, potassium, magnesium, and phosphorus. After alteration by canopy and tree trunk the amount from largest to smallest in the net rainfall is as follows: plot 1, sodium, sulfate, potassium, calcium, magnesium, phosphorus; plot 23, potassium, sodium, sulfate, calcium, magnesium, phosphorus. Basswood (plot 23) has the greatest amount of calcium, magnesium, potassium, and phosphorus in the net rainfall. Except for potassium, bur oak (plot 1) had the lowest values. For green ash (plot 14), sodium and sulfate values are the highest, whereas calcium, magnesium, and phosphorus are intermediate, and potassium the lowest of the three species. These differences suggest foliar leaching that has species specificity occurs.

Thus, in general, net rainfall is highest in chemical elements under basswood, intermediate under green ash, and lowest under bur oak. Aside from the fact that basswood has the highest percentage interception of the gross rainfall, it still has a very large input of chemical elements relative to the other two species. The differences in the nature of the leaf surfaces of these three species, mentioned previously as a possible factor in differential interception of gross rain, could also play a role in alteration of the chemical characteristics of this rain.

Litter Production

The amounts of litterfall collected monthly from May 18 through October 15 beneath the bur oak, green ash, and basswood canopies are shown in Table 22. As expected, there is considerable variability in amount of litter during the collecting period. Slightly higher levels of nonwoody litter from May 18 to June 15 are attributed to collection of flowers, immature fruits, and bud scales dropping from the trees during this period. The amount of nonwoody litter increased again beginning with the August 15 collecting period. The maximum levels occurred during the October 15 collecting period. Woody litter, due to natural pruning or wind breakage, varies considerably among the three species indicating possible differences in times of natural pruning. Plot 1, dominated by bur oak, shows two peak periods of loss. The smallest occurred during the August collecting period, the largest during the October collecting period. The loss under basswood (plot 23) was high during the June collecting period, dropped during July and August, and then increased during September and October. Unlike plots 1 and 23, plot 14, dominated by green ash, had one peak which occurred during the June collecting period.

When compared on a seasonal basis, the total litterfall values in g/m^2 (Table 22) are as follows: bur oak, 265.2 (nonwoody 216.4 and woody 48.8); basswood, 263.1 (nonwoody 226.0, woody 37.2); green ash, 247.4 (nonwoody 208.9, woody 38.5). Little difference is noted when comparison is made between woody and nonwoody weights and the total weights for each of the three plots.

TABLE 22

MEAN WEIGHTS OF WOODY AND NONWOODY LITTER COLLECTED FROM FOUR LITTER TRAPS EACH IN PLOTS 1, 14, AND 23 ON A MONTHLY BASIS FROM MAY 18 TO OCTOBER 15, 1971

Date	Litter type	Plot 1 Mean weight (g/m^2)±SD	Plot 14 Mean weight (g/m^2)±SD	Plot 23 Mean weight (g/m^2)±SD
6-15	woody	8.3± 3.08	17.5±27.17	6.9± 5.66
6-15	nonwoody	9.9± 1.20	9.9± 0.91	10.5± 2.78
7-15	woody	4.6± 2.46	4.7± 1.12	2.5± 1.77
7-15	nonwoody	2.5± 0.98	5.2± 0.91	6.0± 0.97
8-15	woody	15.8±13.92	5.7± 3.16	4.1± 4.10
8-15	nonwoody	7.0± 3.51	11.6± 7.04	13.0± 3.15
9-15	woody	2.1± 1.39	4.2± 3.32	10.9±12.24
9-15	nonwoody	38.9±33.14	51.3± 6.55	51.4±34.67
10-15	woody	17.9± 9.52	6.2± 1.48	12.6± 8.44
10-15	nonwoody	158.1±53.36	130.8±38.96	145.1±23.41
seasonal	woody	48.8± 6.19	38.5± 4.99	37.2± 3.87
seasonal	nonwoody	216.4±58.81	208.9±47.48	226 ±52.53
seasonal	total	265.2	247.4	263.2

The levels of chemical elements found in woody and nonwoody litter samples are shown in Table 23. Seasonal variations exist between levels in woody and nonwoody litter in the same plot and among the three plots. In comparing woody and nonwoody litter, several trends are apparent which hold true for all three plots. Most noticeable is the high level of calcium in woody as opposed to nonwoody litter (Table 23). Three other elements, strontium, iron, and aluminum, are higher in the woody litter in all three plots. The opposite is true for the levels of magnesium, potassium, and phosphorus which are higher in nonwoody than woody tissue. Among the other chemical elements measured, levels in the woody and nonwoody tissue are more variable than the aforementioned ones. In most cases, zinc and sodium are higher in woody litter. The levels of the remaining two elements, copper and manganese, vary considerably in woody and nonwoody litter both within and among plots. Generally, manganese and copper levels are higher in nonwoody litter collected in plots 1 and 23 and lower in plot 14.

Using both litter weights and concentration of chemical elements in the litter, values for seasonal input per unit area were calculated. These values, similar to those for rainfall, designate rate of input of chemical elements per collecting season. Table 24 shows the input of these chemical elements in kilograms per hectare for woody and nonwoody litter and their totals. Among the 11 elements measured, calcium followed by potassium had the highest amount of input and copper the lowest in woody and nonwoody litter in the three plots. Plot 23 had the largest

TABLE 23

LEVELS OF MAJOR CATIONS, PHOSPHOROUS, AND TRACE METALS IN WOODY AND NONWOODY LITTER COLLECTED MONTHLY FROM MAY 18 TO OCTOBER 15, 1971 IN PLOTS 1, 14, AND 23

Date	Litter type	Percentage dry weight				ppm						
		Ca	Mg	K	P	Cu	Sr	Mn	Zn	Fe	Al	Na
						Plot 1						
6-15	W[a]	2.28	0.22	0.40	0.12	27.5	35.1	478.7	72.3	378.7	527.5	88.6
6-15	N[b]	0.87	0.34	0.59	0.12	15.0	9.3	517.6	78.1	463.7	241.3	109.1
7-15	W	1.83	0.16	0.29	0.10	4.4	30.5	302.7	73.5	691.3	601.3	82.3
7-15	N	0.77	0.28	0.56	0.23	20.9	9.5	316.4	71.9	347.5	385.0	71.4
8-15	W	1.78	0.16	0.25	0.10	4.4	30.7	352.9	63.2	843.7	917.5	81.6
8-15	N	0.82	0.26	0.61	0.18	9.7	11.6	271.4	45.0	190.0	228.7	69.4
9-15	W[c]	2.17	0.18	0.45	0.07	12.0	32.5	372.0	372.5	420.0	740.0	109.0
9-15	N	0.73	0.18	0.75	0.17	18.1	9.0	152.0	35.9	212.5	226.2	63.5
10-15	W	2.14	0.15	0.25	0.13	16.3	35.0	370.5	76.3	921.3	953.7	76.5
10-15	N	1.37	0.34	0.25	0.27	6.7	14.9	414.4	41.1	132.5	232.5	49.0
						Plot 14						
6-15	W[c]	1.59	0.17	0.48	0.08	29.5	27.5	310.5	72.5	270.0	375.0	62.0
6-15	N	1.06	0.34	0.73	0.03	19.9	11.9	394.0	332.0	496.2	380.0	107.0
7-15	W	1.83	0.14	0.31	0.10	31.9	30.1	330.4	394.0	900.0	982.5	79.3
7-15	N	1.21	0.30	0.73	0.26	14.7	14.6	257.4	246.0	467.5	497.5	78.0
8-15	W[c]	1.53	0.15	0.31	0.10	13.5	27.0	255.5	96.0	495.0	670.0	88.5
8-15	N	1.45	0.32	0.71	0.21	10.4	18.0	170.7	190.0	221.3	275.0	70.9
9-15	W[c]	1.88	0.12	0.23	0.06	14.5	31.5	262.5	435.0	290.0	435.0	68.0

TABLE 23--Continued

		Percentage dry weight				ppm						
Date	Litter type	Ca	Mg	K	P	Cu	Sr	Mn	Zn	Fe	Al	Na
9-15	N	2.00	0.33	0.77	0.32	19.0	21.3	158.9	180.5	223.7	205.0	51.0
10-15	W[c]	1.98	0.19	0.48	0.14	31.0	28.5	410.0	99.0	640.0	1025.0	93.0
10-15	N	2.05	0.36	0.39	0.27	6.9	22.6	323.0	165.5	143.7	217.5	45.9
							Plot 23					
6-15	W	2.07	0.14	0.31	0.16	21.0	33.9	298.0	146.6	273.7	352.5	70.1
6-15	N	1.78	0.37	1.08	0.37	43.3	20.7	408.9	114.3	538.7	496.3	127.7
7-15	W[c]	2.34	0.13	0.28	0.08	21.5	34.0	288.5	143.5	330.0	465.0	74.5
7-15	N	1.65	0.36	1.16	0.37	17.5	18.4	201.4	73.3	308.7	320.0	92.3
8-15	W[c]	2.44	0.16	0.36	0.11	11.0	35.0	143.0	197.0	255.0	355.0	62.0
8-15	N	1.67	0.29	0.94	0.26	11.6	21.1	152.1	51.3	178.7	213.7	98.3
9-15	W[c]	2.46	0.13	0.27	0.08	17.0	35.0	150.0	948.5	205.0	390.0	122.0
9-15	N	2.08	0.24	0.91	0.34	29.1	23.7	172.1	57.9	191.3	217.5	72.0
10-15	W	2.24	0.16	0.27	0.11	23.4	34.1	371.4	129.6	513.7	566.3	83.1
10-15	N	2.60	0.29	0.69	0.39	9.1	30.0	334.6	55.4	140.0	215.0	48.9

[a] woody litter

[b] nonwoody litter

[c] pooled samples, all others represent a mean

TABLE 24

TOTAL INPUT OF MINERAL ELEMENTS BY WOODY AND NONWOODY LITTER COLLECTED IN PLOTS 1, 14, AND 23 FROM MAY 18 TO OCTOBER 15, 1971

Litter type	kg/ha										
	Ca	Na	Mg	K	P	Cu	Sr	Mn	Zn	Fe	Al
Plot 1											
woody	10.03	0.04	0.79	1.34	0.59	0.006	0.02	0.17	0.04	0.33	0.37
nonwoody	25.89	0.12	6.67	8.21	4.17	0.020	0.03	0.78	0.09	0.32	0.47
total	35.92	0.16	7.46	9.55	4.76	0.026	0.05	0.95	0.13	0.65	0.84
Plot 14											
woody	6.60	0.03	0.62	1.57	0.36	0.011	0.01	0.12	0.05	0.17	0.25
nonwoody	41.02	0.11	7.35	11.12	5.96	0.023	0.04	0.56	0.09	0.40	0.48
total	47.62	0.14	7.97	12.69	6.32	0.034	0.05	0.68	0.14	0.57	0.71
Plot 23											
woody	8.78	0.03	0.48	1.11	0.37	0.007	0.01	0.12	0.04	0.13	0.17
nonwoody	52.58	0.14	6.22	17.87	8.35	0.031	0.06	0.67	0.13	0.40	0.54
total	61.36	0.17	6.70	18.98	8.72	0.038	0.07	0.79	0.17	0.53	0.71

input of calcium, sodium, potassium, strontium, zinc, and copper. The amount of manganese, iron, and aluminum was highest in plot 1. Among the three plots, magnesium was the only element with the highest level of input in plot 14. Similar to net rainfall, the total input of chemical elements by litter is generally higher in plot 23. It also follows the rainfall pattern, in that three of the elements with the highest level of input in plot 23, calcium, potassium, and phosphorus were also highest in the net rainfall under the basswood canopy, in this plot.

Because of damage to the litter traps during the winter of 1971-1972, an accurate assessment of the winter (October 15 to May 18) increment of woody litter was not possible. However, based on collections from a few undamaged traps, this increment was estimated to be 20% of the summer (May 18 to October 15) increment reported for each of the three plots. Therefore, the reported total weights of woody litter must be increased by 20% to obtain the annual input. Assuming the nutrient concentration in the winter woody litterfall to be the same as in that of the summer increment, the levels of nutrient input by woody litter must also be increased by 20%.

Combined Input of Chemical Elements by Throughfall and Litterfall

Out of the chemical elements measured in litterfall and net rainfall, five are common to both. Values for these five when combined (Table 25) give an approximation of the total input of these chemical elements under the canopies of the tree species studied.

TABLE 25

COMBINED TOTALS OF CHEMICAL ELEMENTS MEASURED IN
BOTH LITTERFALL AND NET RAINFALL
IN PLOTS 1, 14, AND 23

	kg/ha				
Plot	Ca	K	Na	Mg	P
1	39.78	22.51	20.20	8.79	5.60
14	53.74	23.56	20.80	9.92	7.78
23	68.41	37.63	17.48	9.36	10.53

A comparison between the two types of input (Tables 21 and 24) reveals that litterfall contributes more to the total amount of calcium, magnesium, and phosphorus than does the net rainfall in all three plots, as expected. However, not all that is added in litterfall is readily available, while net rainfall is. Even in broadleaved woodlands, decomposition would not be so rapid as to allow a readily available supply of ions as does the rainfall and dryfall. Input of potassium by litterfall is higher than by net rainfall in plots 1 and 23 and lower in plot 14. The input of sodium by throughfall is higher in all three plots than by litterfall. Based on the totals, the amounts of calcium, potassium, and phosphorus introduced into each system are noticeably higher in plot 23 than plots 1 and 14, whereas total input of sodium and magnesium is highest in plot 14.

DISCUSSION AND CONCLUSIONS

The Forest River Biology Area has undergone previous disturbance of vegetation by fire, timber cutting, beaver activity, and grazing. The forest, based on tree-ring analysis, is less than 100 years old. These disturbances and the diversity in environments have resulted in a rich vegetation within a small geographic area. The 109 species reported here within the forested part of the 64.8 ha study area constitute about 38% of the 257 species reported in a 200 mile forested study area along the Red River by Wanek (1961).

Ages of trees and their distribution is variable among the community types studied. Bur oak is relatively old, prevalent in community types 1, 2, and 3, and generally restricted to higher elevations. Reproduction by this species is limited. Green ash, also abundant in community types 1, 2, and 3, is generally younger than bur oak, and appears to have grown up where bur oak canopies are more open. Basswoods, generally younger than bur oak and green ash, have their highest density in community type 4, and are located on lower slope positions than bur oak. Paper birch and trembling aspen, found in community type 4, are relatively short-lived species. Elm and box elder are mostly restricted to community type 5 (floodplain). The presence of box elder and elm seedlings and saplings on the slopes indicates these species are spreading up slope from the floodplain. Practically no reproduction by elm and box elder occurs in the floodplain area studied. Substantial vegetative reproduction was observed for several tree species. Rings of basal sprouts are abundant for box elder, paper birch, basswood, and green ash. Excavation of soil pits revealed some root sucker sprouts from aspen and green ash.

Based on linear correlation analysis, elevation and slope orientation and, to a lesser degree slope angle, play an important role in determining stand characteristics of vegetation. Results indicate that significant negative correlation exists between aspect and herbaceous cover, and between basal area of trees and elevation. Both correlations are consistent with the results of Siccama et al. (1970) and Bormann et al. (1970) in their mixed-forest study in New Hampshire. The distribution of shrubs in the B_2 stratum is not strongly influenced by elevation. Both the number and coverage values of herbaceous species increases downslope. So, while herbs are more abundant on lower slopes, the shrubs are more uniformly distributed along the slopes. Coverage values of the taller shrubs increase at higher elevations. The success of shrubs at higher elevations may be attributed to the adaptive nature of their deeper root systems. As expected, results from moisture block studies show soil water depletion occurs from the surface downward and reaches the permanent wilting point in the upper part of the rooting zone first. As a result, when no available water exists for the shallow-rooted herbs, it is still available for the shrubs.

Results of this study show that plant species and environmental gradients on the slopes occur in a continuous, overlapping and not discrete fashion. However, pronounced differences in both vegetation and environment do occur between the slopes and the floodplain. This area is in an early stage of succession, and hence, the continuum pattern of vegetation, as described by Ramensky and Gleason (see Whittaker, 1962) and the Wisconsin School (Curtis and McIntosh, 1951) is expected. When character species or characteristic combinations of species are absent, a Braun-Blanquet type association analysis becomes difficult. Although the vegetation varied continuously along the slopes this does not preclude the establishment of arbitrary community types (Becking, 1968). Neither is the occurrence of natural breaks, such as between the slopes and floodplain, inconsistent with the continuum concept. Daubenmire (1966), in discounting the continuum concept, contends that continuous patterns in distribution of vegetation occur only in disturbed areas while discrete communities can be demonstrated where vegetation is in pristine condition. Future ecological studies in this country will have to be conducted in disturbed areas. Few areas with pristine conditions remain and patterns of vegetation must be recognized as they exist.

Several ordination techniques have been proposed to group vegetation objectively. Two of them have been used in this study. Although Swan-Dix-Wehrhahn ordination is an improvement over the Bray and Curtis method in its selection of axes, it was not as effective in this study as principal component analysis. Swan (1972) also indicates having more success using principal component analysis than the Swan-Dix-Wehrhahn ordination. Several other workers (Barkham and Norris, 1970; Erman and Helm, 1971; van Groenewoud, 1964; Jeglum *et al.*, 1971; Walker and Wehrhahn, 1971) attest to the effectiveness of principal component analysis although they did not compare it to the Swan-Dix-Wehrhahn ordination as in this study. When vegetation is heterogeneous, effectiveness of principal component analysis is increased by splitting data into sets. Jeglum *et al.* (1971) increased the extraction by ordinating vegetation as half sets, woody and nonwoody. The extraction reported in this study (56.8%) was higher than both the total set (45.3%) and that done on half sets (47.3%) by Jeglum *et al.* (1971). The vegetation within this study area is not so heterogeneous as to require the splitting of data into sets.

The present study is similar to that of Jeglum *et al.* (1971) because principal component analysis was done using stands as attributes. As they point out, this approach provides more insight into variation in vegetation than by using species as attributes. Unlike some studies previously mentioned, the present one attempted to establish relationships between vegetation and environmental factors using the results of multiple regression analysis. Additionally, unlike the other approaches, the multiple regression analysis provided predictive equations.

The most valuable contribution of regression equations as used in this study is probably not in predicting presence of species as such, but in elucidating environmental factors important in distribution of individual species. When large numbers of species are analyzed, the frequency of occurrence of these factors reveals the relative importance of environmental variables controlling the distribution of communities.

The value of the multiple regression approach can be enhanced considerably by using weighted vegetation parameters such as coverage or density instead of presence values and the resulting predictive equations would provide a more meaningful insight into the problem. The use of this type of data requires elimination of zero values that occur whenever a species is not present. There are at least two ways to eliminate these zero values. First, by studying a large number of sites (perhaps 100 or more) and using data only from those sites where a species occurs. This would still limit the use of regression analysis to those more frequently occurring species because little confidence could be placed in regressions based on small data size. Secondly, and perhaps a more plausible method, would be to replace zero data by quantitative values. Such a method for use in ordination procedures has been devised by Swan (1970). This technique has considerable potential for multiple regression analysis as well. It must be pointed out that multiple regressions, inherently, are a univariate model (Cooley and Lohnes, 1962).

Based on the results of multiple regression analysis, several environmental factors were shown to be important in the distribution of species and community types. These were potential solar beam irradiation, available water capacity, elevation, linear aspect, slope, and potassium.

Potential solar beam irradiation, most frequently retained of all environmental variables in regression equations, provides a quantitative description of energy flow on slopes that is a permanent site factor (Frank and Lee, 1966). Used within a small geographic area as in this study, any differences in cloud cover, dust, and atmospheric moisture are negligible. Potential solar beam irradiation is more valuable than spot readings by light meters and well suited for gradient analysis. It is considerably more useful in assessing differences in vegetation on slopes than on nonsloping areas. When using potential solar beam irradiation, slopes that face east and west, regardless of slope angle, are assigned similar values. This may pose a problem as the heat regime may not be the same on both slopes because the morning sun dries surfaces and the afternoon sun heats the soil (Geiger, 1965). Therefore, the warmest slopes are theoretically southwest-facing. Haase (1970) studied this problem and concluded that the nature of the vegetation determines which slopes will be the warmest and driest.

The second most frequently occurring variable was available water capacity. Soil water, because of its role in maintaining turgor, ion mobility, and transpiration, has been shown to be an important factor in gradient studies (Bakuzis, 1959; Grigal and Arneman, 1970; Loucks, 1962; Mowbray and Oosting, 1968; Wali and Krajina, 1972). Waring and Major (1964) in a study of redwood forests in California, showed that plant species are more sensitive to water than to nutrient levels. Ayyad and Dix (1964) in a grassland study, concluded soil water availability was a function of both aspect and elevation. The last two mentioned parameters were also retained frequently in the regression equations in this study. The other topographic feature, slope angle, also occurred frequently. As slope angles increase on north-facing slopes, the solar irradiation received decreases, while the opposite is true on south-facing slopes. Therefore, slope angle, in addition to aspect, affects the heat regime on north and south slopes.

The dominant influence of water on distribution of vegetation on slopes has been suggested to have such an overriding influence that nutrient factors cannot be isolated (Kine, 1969). In the present study, this was found not to be entirely true because potassium was one of the six most frequently occurring variables in the regression equations. Levels of potassium in the soils studied ranged from 0.28 meq/100 g to 2.19 meq/100 g. Levels in some soils are slightly below the level of 0.30 meq/100 g required for hardwoods (Waring and Major, 1964). Regression equations indicate that elm, American hazelnut, and beaked hazelnut are three of several species whose distribution is influenced by levels of potassium.

The other nutrient factors were retained less frequently than potassium in the regression equations. They appear to be important for a limited number of species, for example, calcium was retained in only four regression equations. This is consistent with the fact that calcium is one of the most abundant elements in the soils in this area.

Distribution patterns of species along established gradients are somewhat variable depending on physiognomy. Generally, trees show a bimodal, shrubs and herbs a unimodal distribution along the gradients. Mature tree forms may have been established here under different conditions than now exist. Because their tolerance changes with age, they are not always good indicators of the present environmental conditions (Becking, 1968). The shorter-lived shrubs and herbs and even young trees are more sensitive to environmental change (Becking, 1957, 1968; Grigal and Arneman, 1970).

A knowledge of topographic characteristics, water and nutrient requirements for immature trees are needed for selection of species for reforestration. By selecting the right species, trees can be planted with the assurance that they will grow. In the present study, elm, aspen, and birch are shown to have considerably narrower ecological amplitudes along soil, water, and nutrient gradients. So, more selectiveness in site locations is required for these species.

When bivariate combinations were used to test distribution of community types along environmental gradients, several resulting patterns were consistent with those of stand ordination of vegetation. Factors making up the bivariate combinations were the same as those selected most frequently by multiple regression analysis. The fact that potential solar beam irradiation in combination with several other factors gave patterns consistent with stand ordination suggests that it is one of the major ordination axes. Comparison of the potential solar beam irradiation gradient (Figure 5) and the two-dimensional ordination (Figure 32) reveals axis 2 of the ordination parallels the potential solar beam irradiation gradient. Axis 1 does not correspond to any one gradient but presumably a number of gradients referred to by Whittaker (1967) as a "complex gradient." Therefore, studies conducted in smaller geographic areas must employ more quantified gradients than broad regional studies where major gradients are more obvious. Present systems of gradient analysis developed by Whittaker and others favor use of one or two major gradients. There is a need to develop methods to quantitatively assess the importance of more than two environmental gradients in vegetation-environment studies. Multivariate statistical methods such as principal component analysis and multiple regressions should aid in the understanding of multidimensional systems.

Because the vegetation and environment are so different between the slopes and floodplain, they proved to be useful criteria in evaluating the reliability of the results of the ordinations, multiple regression analyses, and the bivariate combinations. Results from these techniques show groupings of floodplain vegetation and environmental parameters set apart from those on the slopes. This provides additional evidence that the correlative approach as used here can produce patterns of vegetation in relation to environment that are biologically meaningful. Instead of pursuing direct or indirect gradient analysis singly, both were used to reveal vegetation-environment relationships in the present study. The two approaches were brought together by means of two-dimensional models (bivariate combinations) of environmental parameters selected by multiple regression analysis.

Quantified gradient analyses should be the first step in the elucidation of several "process studies" in the context of the general systems approach. Such studies involve the aspects of productivity, of seasonal and annual water and nutrient fluxes through rainfall, stemflow and throughfall inputs, and the annual increments in the production of litter.

Interception and retention of rain water by tree canopies is important because it limits input of water into the soil. Consequently, water intercepted by tree canopies and later evaporated is unavailable for plant growth. Water held by the canopy as a result of interception of rainfall is not a complete loss because the energy used to evaporate it cannot be used to evaporate water from the soil (Clements, 1971). Interception ranges from 6 to 48% have been reported for hardwoods in the eastern United States (Kittredge, 1948). Values determined in the present study (bur oak, 11.4%; green ash, 12.3%; and basswood, 29.3%) are within this range. The relatively large amount of interception by the basswood canopy may have some bearing on the conspicuous lack of understory and ground cover observed under these trees. Although the reduction of light by the dense canopies seems to be the most obvious explanation, this may not be the case.

The total amount of water supplied to soil as stemflow contributed less than 1% of that supplied by throughfall under the three tree species studied. Stemflow values of from 0.5 to 8.7% of the net annual throughfall are reported for hardwoods in the eastern United States (Helvey and Patric, 1965). While stemflow does not account for a large input of water to the forest floor, it does supply water and nutrients to a localized region around the tree. Higher levels of organic carbon and exchangeable potassium and lower pH have been shown to result from stemflow water in soil around trunks of American beech (Gersper and Holowaychuk, 1971).

Although the small amounts of stemflow collected from the bur oak trunk were partially attributed to the leakage by the collecting girdle, this loss could also be attributed to the rough texture of the oak bark. In trees with rough bark, water drops from projections of bark instead of flowing down it (Helvey and Patric, 1965). Gersper and Holowaychuk (1971) attributed the small amount of stemflow collected from white oak to its rough, fissured bark.

Results of the present study show that alteration of rainfall by tree canopies does occur and the alteration is different for each species studied. Rain falling through leaves picks up minerals in two ways: (1) washing of the dust from leaf surfaces and (2) leaching from the leaf tissues. Carlisle, Brown, and White (1966) were reluctant to point out that enrichment was due to leaching of leaves because of the possibility that materials could have been washed from leaf surfaces. Attiwill (1966), however, suggests that dust added to the canopies also falls through into the rain guages. Therefore, any differences in enrichment is attributable to alteration by the canopies.

Two main kinds of evidence have been given for foliar leaching. One, studies using radioactive tracers by Thomas (1969), Tukey (1966), Witherspoon (1964), and others have shown that radioactive mineral elements are leached. Secondly, changes in ionic ratios in rainfall after it passes through the canopy provides further evidence for foliar leaching. By comparing ratios of ions in rainfall before and after it passed through tree canopies, Attiwill (1966) concluded foliar leaching does occur.

The order of removal of mineral elements from gross rainfall by the canopies is as follows: (1) bur oak, potassium > magnesium > phosphorus > calcium > sodium, (2) green ash, potassium > calcium > phosphorus > sodium > magnesium, and (3) basswood, potassium > calcium > magnesium > phosphorus. Whether these changes are caused by foliar leaching is unknown, but changes in ratios of these ions strongly suggest that foliar leaching is occurring. The sequence of removal of the mineral elements from tree canopies (shown above) does not include sodium for basswood or sulfates for all three species because the canopies take up these elements.

Interestingly, potassium, which is removed in large amounts by all three species studied, is in short supply in the soil. It appears that potassium plays an important role in the nutrient budget of this ecosystem.

The nature of the surface of the leaves has an influence on leaching. Tukey (1966) has shown that leaves with waxy surfaces are difficult to wet and are less susceptible to leaching losses. Bur oak and green ash leaves, because of their waxy surfaces, have less interception of gross rainfall and less enrichment of throughfall than basswood. The denseness of the basswood canopy as opposed to sparseness of oak and ash canopies plays an important role in increasing interception.

Total input of mineral elements by throughfall and stemflow was based on samples collected from May 18 to October 15, 1971. This coincides with the period from before the leaves appeared to shortly after leaf fall. About three-fourths of the yearly rainfall occurs during this period. Less mineral elements are added to the ecosystem by snow than by rain. However, input of minerals does occur from October 15 to May 18, indicating that the totals reported here represent an underestimation of the annual total.

Comparable data for nutrient input by throughfall and stemflow for the species studied here are lacking. Reiners (1972) studied annual input by throughfall in oak forests (Quercus ellipsoidalis and Q. alba) in east-central Minnesota. He reports annual input of calcium, magnesium, and phosphorus to be 7.6, 3.1, and 0.8 kg/ha. By including stemflow, these values are estimated by Reiners to increase by about 10%. Results from the sites in the Biology Area in kg/ha, show the following range: phosphorus, 0.8 to 1.8; potassium, 10.9 to 18.6; calcium, 3.9 to 7.1; magnesium, 1.3 to 2.7; and sodium, 17.3 to 20.7. Gross rainfall measured by Reiners (1972), 62.4 cm, was nearly twice as much during the same length of collecting period as in the present study (35.2 cm). Similarly, calcium, magnesium, and phosphorus levels are almost twice as high in the oak forest in Minnesota as under the oak canopy here.

A consideration of sulfate levels in rain water is important because sulfur is an essential element required for plant growth. High levels indicate air pollution. The sulfate in the atmosphere may originate by oxidation of hydrogen sulfide from organic compounds or from sulfur dioxide as a result of burning of fuels (coal, oil, and gas) containing sulfides. Sulfur dioxide reacts with oxygen and hydrogen in the air to form sulfuric acid. As determined here, levels of sulfate in rainfall are reduced by tree canopies (possibly foliar absorption). This suggests that these species may have a modifying effect in purifying the air.

There is need for further study of input of rainfall and dustfall because together they provide a substantial pool of nutrients readily available to plants. Further studies are needed on alteration of the chemical composition of rain water by tree canopies for providing information on nutrient physiology of each species.

Litterfall represents another important source of nutrients, although not immediately available, for plant growth. The total weight of litter produced in the plots studied ranged from 247 to 265 g/m^2. Inclusion of the winter increment, estimated to be 20% of the measured woody litterfall, increases values from 7 to 10 g/m^2. A comparative value for temperate forests of 463 g/m^2 in an oak forest in Minnesota is reported by Reiners and Reiners (1970). Low litter production in the Forest River Biology Area is in part due to the low vegetation density. The tree density is about one-half that of the oak forests studied by Reiners and Reiners (1970). Located at higher latitude, the study area receives less solar energy than mid-latitudes. Rainfall during the growing season is low and appears to be an important factor in the amount of litterfall produced.

Although total litter production is similar in the three sites, the amounts of mineral elements contributed by litterfall in each varies considerably. For example, input of calcium, potassium, and phosphorus under basswood was between one and one-half to two times that of bur oak, while that of green ash was intermediate to the other two. While total weight of litter production is low compared to other reported values from deciduous forests, this is not true for input of mineral elements, especially calcium, by litterfall. Calcium levels ranged from 35.9 to 61.4 kg/ha as compared to 49.6 kg/ha in oak forests in Minnesota (Reiners and Reiners, 1970) and 19.8 kg/ha in beech forests in Sweden (Nihlgard, 1972). Calcium is very abundant in soils here. Levels of sodium in litterfall is very low (0.1 to 0.2 kg/ha) compared to 17.0 kg/ha reported by Woodwell and Whittaker (1967) in an oak-pine forest in New York. Iron and manganese levels in litter are not frequently reported. Values here are low (iron, 0.5 to 0.6; manganese, 0.7 to 0.9 kg/ha) compared to those (iron, 4.5; manganese, 7.0 kg/ha) in beech forests in south Sweden (Nihlgard, 1972). Neither of these nutrients seems to be in short supply in soils studied in the Forest River Biology Area.

The amount of the most abundant mineral elements in litter collected during this study is as follows: calcium>potassium>magnesium> phosphorus. This order is the same as that reported for deciduous forests in Russia (Rodin and Bazilevich, 1967).

Input of mineral elements into forest floors on a long term basis can be accounted for by measuring contributions by both rainfall and litterfall. It is this rate of input which is important in maintaining a mobile pool from which plants can obtain nutrients essential for growth. Reported total input of mineral elements by combined throughfall, stemflow, and litterfall reflect the annual rate of the nutrient cycle. Total input of calcium, potassium, magnesium, phosphorus, and sodium in kg/ha within the three sites range from 39.8 to 68.4, 22.5 to 37.6, 8.8 to 9.9, 5.6 to 10.6, and 17.5 to 20.8, respectively. The values of these mineral elements reported by Nihlgard (1972) in the beech forests are 33.7, 35.9, 8.3, 5.2, and 22.6 kg/ha, respectively. Comparisons of similar values in an oak forest in Minnesota (Reiners, 1972) are available for only three mineral elements. These levels in kg/ha are as follows: calcium, 58.2; magnesium, 13.5; and phosphorus, 6.2. In the Biology Area, levels of calcium are higher, other levels of elements are similar to the aforementioned studies.

Considerable input of nutrients has been demonstrated by both rainfall and litterfall. Failure to include both in future studies would result in a serious underestimate of nutrient input. In addition, increments added by herbaceous litter and alteration of rainwater by this stratum should be taken into consideration in assessing the rate of nutrient input. By expanding this approach to include nutrient uptake by vegetation, nutrient input by decaying roots, and leaching losses from the forest floor, the nutrient budget for this forest ecosystem can be established.

APPENDIX A

List of Species Occurring in 40 Plots Studied

VASCULAR PLANTS

Acer negundo L.
Actaea rubra (Ait.)Willd.
Agastache foeniculum (Pursh)Ktze.
Agropyron trachycaulum (Link)Malte
Agrostis scabra Willd.
Amelanchier alnifolia Nutt.
Amorpha canescens Pursh
Amphicarpa bracteata (L.)Fern.
Anemone canadensis L.
A. virginiana L.
Apocynum androsaemifolium L.
Aquilegia canadensis L.
Arabis hirsuta (L.)Scop.
Aralia nudicaulis L.
Arctium minus (Hill)Bernh.
Arisaema atrorubens (Ait.)Blume
Aster sagittifolius Wedem.
Avena fatua L.
Betula papyrifera Marsh.
Botrychium virginianum (L.)Sw.
Bromus inermis Leyss.
Carex assiniboinensis W. Boott
C. deweyana Schwein.
C. eburnea Boott
C. peckii Howe
C. pennsylvanica Lam.
C. rosea Schkuhr.
C. saximontana Mack.
C. sprengelii Dew.
C. tetanica Schkuhr.
Celastrus scandens L.
Corallorhiza maculata Raf.
Cornus stolonifera Michx.
Corylus americana Walt.
C. cornuta Marsh.
Crataegus chrysocarpa Ashe
Elymus virginicus L.
E. virginicus var. *submuticus* Hook.

Erigeron glabellus Nutt.
Festuca obtusa Biehler.
Fragaria virginiana Duchesne
Fraxinus pennsylvanica Marsh. var. *subintegerrima* (Vahl)Fern.
Galium aparine L.
G. boreale L.
G. triflorum Michx.
Heliopsis helianthoides (L.)Sweet
Humulus lupulus L.
Hydrophyllum virginianum L.
Hystrix patula Moench.
Laportea canadensis (L.)Wedd.
Lappula cenchrusoides A. Nels.
Lathyrus ochroleucus Hook.
Leonurus cardiaca L.
Lithospermum incisum Lehm.
Lonicera dioica L.
Maianthemum canadense Desf.
Menispermum canadense L.
Monarda fistulosa L.
Nepeta cataria L.
Oryzopsis asperifolia Michx.
O. racemosa (Sm.)Ricker
Osmorhiza longistylis (Torr.)DC.
Ostrya virginiana (Mill)K. Koch.
Oxalis europaea Jord.
Parthenocissus inserta (Kerner)K. Fritsch
Phyrma leptostachya L.
Poa pratensis L.
Polygonatum canaliculatum (Muhl.)Pursh
Populus tremuloides Michx.
Prenanthes alba L.
Prunus pennsylvanica L.
P. virginiana L.
Pyrola secunda L.
Quercus macrocarpa Michx.
Rhus radicans L. var. *rydbergii* (Small)Rehd.
Ribes americanum Mill.
R. missouriense Nutt.
Rosa blanda Ait.
Rubus idaeus L.
Rudbeckia laciniata L.
Sanicula marilandica L.
Schizachne purpurascens (Torr.)Swallen
Scrophularia lanceolata Pursh
Smilacina racemosa (L.)Desf.

S. stellata (L.)Desf.
Smilax herbacea L.
Solidago gigantea Ait.
S. nemoralis Ait.
Sphenopholis intermedia Rydb.
Stellaria longifolia Muhl.
Symphoricarpos albus (L.)Blake
S. occidentalis Hook.
Taraxacum officinale Weber
Thalictrum dasycarpum Fisch. & Lall.
T. venulosum Trel.
Tilia americana L.
Trillium cernuum L.
Ulmus americana L.
Urtica procera Muhl.
Viburnum lentago L.
V. rafinesquianum Schultes var. *affine* (Bush)House
V. trilobum Marsh.
Vicia americana Muhl.
V. angustifolia Reichard
Viola papilionacea Pursh
V. pennsylvanica Michx.
V. rugulosa Greene
Vitis vulpina L.
Zizia aurea (L.)Koch

MOSSES

Amblystegium serpens (Hedw.)B.S.G.
Anomodon minor (Hedw.)Furnr.
Brachythecium sp.
Campylium hispidulum var. *sommerfeltii* (Myr.)Lindb.
Frullania sp.
Leskea arenicola Best
Mnium cuspidatum Hedw.
Orthotrichum stellatum Brid.
Platydictya subtile (Hedw.)Crum
Pylaisiella polyantha (Hedw.)Grout

LICHENS

Caloplaca aurantiaca (Lightf.)Th.Fr.
Candelaria concolor (Dicks.)B. Stein
Parmelia bolliana Mull. Arg.
P. flaventior Stirt.
P. subaurifera Nyl.
P. ulophyllodes (Vain.)Sav.

Physcia aipolia (Ehrh.)Hampe
P. elaeina (Sm.)A.L.Sm.
P. grisea (Lam.)Zahlbr.
P. orbicularis (Neck.)Poetsch
P. stellaris (L.)Nyl.
Ramalina sinensis Jatta
Teloschistes chrysophthalmus (L.)Th.Fr.
Xanthoria fallax (Hepp)Arn.
X. polycarpa (Ehrh.)Oliv

APPENDIX B

Physical and Chemical Analyses of Soils from 40 Plots Studied

Explanation of the symbols used:

I. Physical analyses for each horizon

P = plot

H = horizon (2 represents the humus layer)

RD = rooting depth in centimeters

BD = bulk density, grams per cubic centimeter

1/3 = percentage water by weight at 1/3 bar soil water tension

15 = percentage water by weight at 15 bar soil water tension

1/3-15 = water retension capacity, percentage water by weight

AWC = available water capacity in centimeters per centimeters of soil depth

II. Chemical properties for each horizon

P = plot

H = horizon

D = type of determination

W = determinations on water-extractable fractions for pH; specific conductivity; Ca, Na, Mg, K in millequivalents per liter

R = determination of pH with 0.01 molar $CaCl_2$ and ammonium acetate-extractable Ca, Na, Mg, K in millequivalents per 100 grams

Cond. = specific conductivity in micromhos per centimeter

%OM = percentage organic matter

CEC = cation exchange capacity in millequivalents per 100 grams

III. EDTA-extractable trace elements in each horizon in parts per million

P = plot

H = horizon

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
01-2	2-0	0.65	40.3	29.8	10.4	0.1			
01-3	0-20	1.00	28.6	14.2	14.4	2.7	60.7	15.4	23.8
01-4	20-45	1.18	30.8	12.0	18.7	5.1	44.3	27.6	29.9
01-5	45-62	1.20	24.4	11.0	13.4	2.5	50.3	21.3	28.3

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
01-2	W	7.6	241.4	17.6		6.0	3.9	8.2	5.5	12.0
01-2	R	6.6			93.9	14.2	0.6	5.4	1.0	
01-3	W	7.7	344.8	3.4		4.0	1.1	2.6	0.6	5.0
01-3	R	7.3			90.9	15.5	0.1	3.5	0.5	
01-4	W	7.4	216.0	1.1		2.6	1.2	1.8	0.4	3.0
01-4	R	6.9			55.2	15.4	0.3	4.2	0.5	
01-5	W	7.6	267.0	1.2		2.7	0.8	1.4	0.2	3.0
01-5	R	6.7			48.2	13.5	0.2	3.7	0.3	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
01-2	1.6	517.0	12.8	9.7	303.5	7.0	179.0	166.5	4.3
01-3	1.1	510.5	5.4	11.1	184.0	3.0	155.0	136.0	4.1
01-4	2.2	159.5	1.8	2.8	35.5	2.0	73.0	56.5	4.3
01-5	2.3	80.5	1.7	2.3	25.5	1.5	72.5	59.5	3.9

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
02-2	3-0	0.8	43.1	34.7	8.4	0.2			
02-3	0-16	1.00	36.6	19.5	17.0	2.6	53.3	26.1	20.5
02-4	16-26	1.08	28.9	12.3	16.6	3.2	52.4	27.2	20.3
02-5	26-55	1.14	23.4	10.4	13.0	3.9	47.8	26.3	25.7

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
02-2	W	7.6	362	14.9		9.1	4.5	10.4	8.0	34.0
02-2	R	6.9			113.1	16.0	1.1	5.4	1.2	
02-3	W	7.7	405	8.9		5.5	0.8	3.0	1.3	11.0
02-3	R	7.3			87.3	21.2	0.6	4.1	0.8	
02-4	W	7.5	233	1.5		2.9	1.3	1.5	0.9	1.0
02-4	R	6.8			68.8	12.9	0.4	3.3	0.9	
02-5	W	7.8	267	1.8		5.7	0.9	1.5	1.1	1.0
02-5	R	6.7			64.3	13.7	0.4	2.9	0.6	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
02-2	2.0	515.5	14.8	8.3	193.5	5.5	115.0	141.5	7.8
02-3	1.6	511.5	10.0	8.3	134.0	2.5	99.0	150.5	4.8
02-4	2.3	324.5	4.1	3.7	43.0	1.5	88.0	58.5	3.1
02-5	2.5	128.0	2.3	2.6	34.0	0.5	79.0	62.0	3.7

I

P H	RD	BD	% water by weight			AWC	%		
			1/3	15	1/3-15		Sand	Silt	Clay
03-2	3-0	0.8	33.8	26.7	7.1	0.1			
03-3	0-55	0.93	32.4	15.2	17.1	8.7	64.8	14.6	20.4
03-4	55-78	1.12	25.9	15.4	10.4	2.6	56.2	15.3	28.4

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
03-2	W	7.4	396.6	12.2		3.0	3.8	5.0	6.1	66.0
03-2	R	6.2			117.7	12.0	0.8	4.0	1.2	
03-3	W	7.3	146.6	5.1		1.2	1.2	0.7	0.3	38.0
03-3	R	7.3			82.1	11.8	0.1	2.5	0.6	
03-4	W	7.0	121.0	0.4		1.0	0.9	0.6	0.1	23.0
03-4	R	5.6			58.0	8.6	0.4	4.2	0.5	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
03-2	1.6	516.5	19.8	9.1	473.0	5.0	231.0	143.5	5.2
03-3	1.1	513.0	21.0	10.4	441.0	4.5	205.0	146.0	3.7
03-4	1.0	511.5	4.4	9.5	380.5	4.5	254.0	394.5	3.7

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
04-2	3-0	0.7	66.7	37.0	29.6	0.6			
04-3	0-37	0.76	29.6	16.7	12.9	3.5	63.7	9.6	26.6
04-4	37-67	1.13	28.6	14.4	14.2	4.7	58.3	18.7	22.9
04-5	67-68	1.26	23.4	13.7	9.6	0.1	61.3	12.7	25.9

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
04-2	W	7.6	672.4	17.6		1.0	3.8	7.1	8.5	55.0
04-2	R	6.6			107.9	16.2	1.0	4.5	1.5	
04-3	W	7.4	241.4	7.9		2.8	1.1	2.0	1.3	68.0
04-3	R	7.2			101.7	16.7	0.5	3.9	1.4	
04-4	W	6.6	95.0	1.3		0.3	1.1	0.3	0.2	26.0
04-4	R	5.7			98.8	7.7	0.4	3.3	0.9	
04-5	W	6.9	86.0	0.7		0.5	0.7	0.3	0.2	21.0
04-5	R	5.6			56.0	8.0	0.5	3.9	1.2	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
04-2	1.9	518.0	21.5	9.4	383.0	6.5	150.0	148.0	5.6
04-3	1.2	515.5	19.1	8.7	425.5	4.5	221.0	153.0	3.2
04-4	1.0	516.0	11.6	14.3	243.0	4.5	230.0	306.0	3.7
04-5	0.9	513.0	4.0	12.7	408.0	4.0	225.0	169.5	3.1

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
05-2	3-0	0.65	39.5	28.2	11.2	0.2			
05-3	0-52	0.68	28.2	17.0	11.2	3.9	69.9	12.1	17.9
05-4	52-65	1.00	17.6	11.0	6.5	0.8	75.6	6.1	18.2

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
05-2	W	7.6	551.7	21.7		6.4	3.6	7.1	6.2	2.0
05-2	R	6.2			181.3	21.0	1.2	5.8	1.4	
05-3	W	7.1	103.4	4.1		0.8	1.3	0.7	0.3	2.0
05-3	R	7.2			68.7	15.0	0.2	3.4	0.8	
05-4	W	7.1	112.0	0.6		1.0	0.8	0.4	0.1	2.0
05-4	R	5.5			25.2	6.6	0.5	2.9	0.6	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
05-2	2.4	518.0	28.1	9.9	498.5	9.5	178.0	153.0	6.0
05-3	1.1	513.5	15.4	7.5	541.0	3.5	286.0	108.5	3.1
05-4	1.0	509.5	3.2	6.9	437.0	2.5	212.0	185.5	3.6

I

P H	RD	BD	% water by weight				%		
			1/3	15	1/3-15	AWC	Sand	Silt	Clay
06-2	3-0	0.75	52.0	40.4	11.6	0.1			
06-3	0-12	0.80	40.1	20.0	20.0	1.9	57.9	17.2	24.8
06-4	12-27	0.90	30.9	13.1	17.7	2.3	64.4	10.0	25.4
06-5	27-56	1.04	20.6	12.2	8.3	2.1	66.7	10.1	23.1

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
06-2	W	7.5	551.7	21.7		4.6	4.0	6.4	7.3	73.0
06-2	R	6.1			151.6	17.2	0.9	5.4	1.5	
06-3	W	7.5	241.4	8.5		3.6	1.0	1.8	0.6	65.0
06-3	R	7.1			110.8	18.8	0.1	4.2	0.9	
06-4	W	6.4	103.0	2.2		0.4	1.3	0.3	0.2	49.0
06-4	R	5.1			104.0	6.3	0.3	2.8	0.7	
06-5	W	6.7	78.0	0.8		0.4	0.8	0.2	0.1	23.0
06-5	R	5.0			47.1	6.8	0.4	3.0	0.7	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
06-2	2.0	518.5	26.3	8.8	550.5	8.0	198.0	129.0	5.2
06-3	1.5	516.5	24.7	6.9	489.0	5.0	218.0	127.5	3.3
06-4	0.9	515.0	4.8	7.4	502.0	3.5	262.0	166.0	2.3
06-5	1.0	512.0	1.9	7.2	406.0	3.0	254.0	386.0	2.1

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
07-2	2-0	0.75	51.4	41.8	9.6	0.1			
07-3	0-14	0.89	38.4	17.3	21.0	2.5	55.4	19.7	24.8
07-4	14-26	0.92	28.5	14.3	14.2	1.5	57.7	16.0	26.1
07-5	26-65	1.08	23.0	10.7	12.2	3.5	51.5	22.7	25.7

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
07-2	W	8.0	603.4	25.0		6.0	2.4	6.6	8.6	58.0
07-2	R	6.8			127.8	21.2	0.6	5.1	1.4	
07-3	W	7.7	327.6	9.2		4.9	3.2	2.0	1.5	61.0
07-3	R	7.3			97.1	21.9	0.5	3.8	1.3	
07-4	W	7.1	216.0	1.5		0.9	1.4	0.9	0.9	52.0
07-4	R	6.4			70.4	8.6	0.3	3.3	1.1	
07-5	W	7.3	216.0	1.0		1.6	1.4	0.7	0.6	22.0
07-5	R	6.5			68.9	12.1	0.4	3.4	0.9	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
07-2	2.1	517.0	27.8	8.3	322.5	6.5	127.0	136.5	5.6
07-3	1.7	513.5	21.1	9.5	521.5	4.5	154.0	145.5	4.0
07-4	1.2	514.0	5.2	16.8	292.7	4.5	232.0	157.0	3.2
07-5	1.9	323.0	1.8	4.0	89.0	1.5	89.0	77.5	7.2

I

				% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
08-2	2-0	0.6	50.8	37.5	13.3	0.1			
08-3	0-28	0.67	34.7	21.3	13.3	2.4	69.3	13.6	17.0
08-4	28-46	1.19	11.4	7.5	3.9	0.7	74.2	7.5	18.1

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
08-2	W	8.1	448.3	20.3		4.5	2.4	6.7	4.9	47.0
08-2	R	6.9			121.3	20.2	0.8	5.4	1.0	
08-3	W	7.7	258.6	6.5		3.5	1.0	1.7	0.5	27.0
08-3	R	7.3			67.8	19.7	0.1	4.0	0.6	
08-4	W	7.3	181.0	0.9		2.0	0.8	0.8	0.2	5.0
08-4	R	6.6			16.9	11.4	0.4	2.4	0.4	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
08-2	1.9	515.5	21.1	8.4	313.5	5.5	118.0	138.5	4.6
08-3	1.4	511.0	19.1	6.1	289.0	2.5	140.0	105.5	3.1
08-4	1.7	238.5	1.9	2.0	56.5	0.5	90.0	51.0	2.1

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
09-2	1-0	0.6	45.1	32.4	12.7	0.0			
09-3	0-14	0.66	37.0	17.5	19.5	1.8	60.2	14.8	24.9
09-4	14-41	0.81	25.5	12.1	13.4	2.9	67.8	14.4	17.6
09-5	41-65	1.11	16.8	11.2	5.5	1.4	74.1	7.6	18.2

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
09-2	W	7.7	396.6	19.0		3.8	4.1	6.0	5.6	73.0
09-2	R	6.5			101.0	15.3	0.8	4.4	1.1	
09-3	W	7.7	258.6	8.2		4.1	1.0	1.9	0.8	71.0
09-3	R	7.3			85.2	20.8	0.9	4.3	1.0	
09-4	W	6.7	95.0	2.0		0.3	1.2	0.3	0.2	56.0
09-4	R	5.8			81.8	6.8	0.3	3.0	0.8	
09-5	W	6.8	60.0	1.0		0.5	0.6	0.2	0.1	40.0
09-5	R	5.2			42.8	6.3	0.5	3.1	0.6	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
09-2	1.7	517.5	13.1	8.4	481.5	6.0	182.0	136.0	4.4
09-3	1.6	516.5	9.2	8.3	467.1	4.5	188.0	154.5	2.6
09-4	0.9	515.5	3.5	8.6	543.5	2.5	267.0	236.5	2.3
09-5	0.7	510.5	2.9	9.2	774.5	1.5	331.0	861.5	2.7

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
10-2	2-0	0.65	42.1	33.6	8.4	0.1			
10-3	0-29	0.84	28.4	20.6	7.8	1.8	69.1	11.1	19.7
10-4	29-48	1.08	23.4	11.0	12.4	2.5	70.1	8.5	21.2
10-5		1.24	18.5	10.4	8.0		68.0	8.6	23.3

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
10-2	W	7.8	396.6	15.4		3.2	3.7	6.6	4.9	65.0
10-2	R	6.6			92.6	15.4	0.8	4.1	1.0	
10-3	W	7.4	181.0	9.6		2.1	1.1	1.1	0.5	56.0
10-3	R	7.2			63.0	15.6	0.1	3.7	0.8	
10-4	W	6.6	112.0	1.1		0.5	1.1	0.4	0.2	17.0
10-4	R	6.0			57.8	7.0	0.2	2.0	0.5	
10-5	W	6.8	78.0	0.4		0.5	0.7	0.3	0.0	17.0
10-5	R	5.8			40.8	6.6	0.3	3.4	0.4	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
10-2	1.0	514.0	40.3	10.5	32.0	5.5	122.0	90.0	3.5
10-3	0.5	513.0	38.0	10.5	334.0	2.5	131.0	80.0	3.0
10-4	0.5	513.5	6.0	13.0	341.0	2.5	168.0	190.0	2.5
10-5	0.5	512.5	3.5	4.5	326.0	2.0	173.0	145.0	3.0

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
11-2	3-0	0.75	54.0	44.6	9.4	0.2			
11-3	0-19	0.80	32.1	17.3	14.8	2.2	66.3	14.7	18.9
11-4	19-34	1.17	22.2	10.0	12.1	2.1	71.1	11.0	17.7
11-5	34-58	1.31	15.2	8.9	6.3	1.9	78.2	3.5	18.1

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
11-2	W	7.9	551.7	25.2		6.4	2.4	7.0	5.7	56.0
11-2	R	6.6			129.1	19.8	0.6	5.3	1.2	
11-3	W	7.3	206.9	6.8		2.4	1.0	1.2	0.5	66.0
11-3	R	7.1			74.7	16.1	0.1	3.8	0.8	
11-4	W	6.5	103.0	0.9		0.3	1.7	0.2	0.3	32.0
11-4	R	5.7			49.1	5.9	0.3	3.0	0.7	
11-5	W	6.7	86.0	0.6		0.3	0.7	0.2	0.2	19.0
11-5	R	5.6			39.5	5.5	0.3	2.7	0.7	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
11-2	1.5	515.0	57.5	10.5	340.5	7.5	173.0	105.0	4.5
11-3	1.0	514.0	43.5	9.0	387.0	2.5	109.0	70.0	2.5
11-4	0.5	514.0	21.5	10.0	327.5	2.0	153.0	115.0	1.5
11-5	0.5	509.5	8.0	9.0	336.5	1.0	191.0	370.0	1.5

I

				% water by weight				%		
P	H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
12-2		2-0	0.65	45.4	35.5	9.9	0.1			
12-3		0-12	0.72	39.0	19.3	19.7	1.6	57.8	22.4	19.1
12-4		12-22	1.02	28.3	12.1	16.2	1.5	49.9	24.6	25.4
12-5		22-53	0.95	24.5	10.2	14.2	3.8	51.3	20.2	28.3

II

P	H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
12-2		W	8.1	534.5	6.1		6.0	2.4	7.6	8.4	29.0
12-2		R	7.1			165.6	20.4	1.3	5.1	1.4	
12-3		W	7.7	362.1	8.9		5.1	0.9	2.0	1.3	25.0
12-3		R	7.3			131.7	26.4	0.2	4.2	1.3	
12-4		W	6.6	267.0	2.4		2.8	1.3	1.2	1.1	8.0
12-4		R	6.7			126.5	14.0	0.2	3.0	0.9	
12-5		W	7.4	250.0	0.6		2.4	1.0	1.2	1.0	8.0
12-5		R	6.7			108.0	13.8	0.3	3.7	1.1	

III

P	H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
12-2		1.5	503.0	28.0	9.0	125.0	4.0	62.0	60.0	2.4
12-3		1.5	472.0	19.0	6.5	83.0	3.0	58.0	40.0	2.5
12-4		1.5	283.5	20.0	6.5	59.5	1.5	51.0	30.0	3.0
12-5		1.5	506.5	28.5	9.5	137.0	4.0	134.0	70.0	4.0

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
13-2	2-0	0.7	55.0	45.6	9.4	0.1			
13-3	0-40	0.78	27.1	13.2	13.9	4.3	67.4	15.5	17.0
13-4	40-55	1.20	19.3	12.2	7.1	1.2	58.9	18.7	22.2

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
13-2	W	7.8	482.8	9.8		4.2	4.7	5.9	5.8	44.0
13-2	R	6.2			133.0	19.6	1.1	5.4	1.3	
13-3	W	7.2	86.2	3.8		0.7	0.9	0.6	0.2	61.0
13-3	R	7.1			54.3	13.1	0.1	3.2	0.6	
13-4	W	6.7	52.0	0.5		0.3	0.7	0.1	0.0	8.0
13-4	R	5.4			28.4	5.9	0.4	3.3	0.5	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
13-2	1.5	516.0	57.0	13.0	407.5	8.0	216.0	95.0	4.5
13-3	0.5	511.0	37.5	9.5	412.0	2.0	182.0	80.0	2.5
13-4	0.5	513.0	5.0	9.5	341.5	2.5	180.0	105.0	1.5

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
14-2	2-0	0.50	65.6	52.0	13.5	0.1			
14-3	0-27	0.53	32.1	14.8	17.2	2.4	70.7	12.0	17.1
14-4	27-38	0.98	18.5	8.9	9.6	1.0	75.3	6.0	18.6
14-5	38-52	1.15	17.4	11.5	5.9	0.9	76.2	6.0	17.7

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
14-2	W	8.0	534.5	26.4		5.6	4.0	6.4	6.4	44.0
14-2	R	6.6			146.0	22.2	0.9	5.3	1.2	
14-3	W	7.3	129.3	7.5		1.0	1.0	1.1	0.3	46.0
14-3	R	7.1			93.5	16.6	0.7	3.6	0.6	
14-4	W	6.3	95.0	1.3		0.3	1.7	0.3	0.2	24.0
14-4	R	5.7			43.9	5.6	0.3	2.6	0.5	
14-5	W	7.0	95.0	0.8		0.7	0.7	0.3	0.2	22.0
14-5	R	5.8			6.3	6.2	0.3	3.3	0.8	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
14-2	1.5	516.0	56.0	10.5	323.5	8.5	104.0	95.0	4.0
14-3	0.5	512.0	37.5	10.0	427.0	2.5	144.0	80.0	2.0
14-4	0.5	511.5	4.5	11.5	295.5	2.0	206.0	125.0	1.5
14-5	0.5	506.5	6.5	9.5	226.0	1.5	209.0	65.0	2.5

I

P H	RD	BD	% water by weight				%		
			1/3	15	1/3-15	AWC	Sand	Silt	Clay
15-2	2-0	0.45	59.4	41.7	17.6	0.1			
15-3	0-15	0.48	34.9	16.2	18.7	1.3	68.2	17.1	14.5
15-4	15-57	1.13	17.7	8.4	9.3	4.4	76.1	6.0	17.8
15-5	57-58	1.24	11.1	7.0	4.0	0.0	76.8	5.0	18.1

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
15-2	W	7.9	482.8	21.7		5.1	2.5	5.8	5.3	34.0
15-2	R	6.4			151.3	19.8	1.5	5.5	1.5	
15-3	W	7.3	172.4	7.2		1.3	0.9	0.9	0.5	39.0
15-3	R	7.1			123.5	16.8	0.2	3.9	1.0	
15-4	W	6.4	86.0	2.2		0.3	1.6	0.3	0.1	16.0
15-4	R	5.5			47.1	5.7	0.2	1.5	0.5	
15-5	W	6.5	52.0	0.6		0.4	0.8	0.1	0.0	9.0
15-5	R	5.4			11.3	4.0	0.3	1.7	0.4	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
15-2	2.0	516.5	40.0	15.0	406.0	11.5	100.0	95.0	5.0
15-3	1.0	513.5	47.0	9.5	401.5	3.0	137.0	50.0	2.5
15-4	0.5	512.0	8.0	11.0	321.0	1.5	165.0	45.0	2.0
15-5	0.5	510.5	3.5	13.0	241.0	1.0	179.0	165.0	1.5

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
16-2	2-0	0.75	61.2	42.8	18.4	0.2			
16-3	0-12	0.86	33.6	17.0	16.6	1.7	68.3	13.7	17.9
16-4	12-53	1.13	18.4	9.5	8.9	3.9	75.2	6.0	18.7
16-5	53-58	1.16	11.6	6.5	5.0	0.2	71.2	8.4	20.2

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
16-2	W	8.0	517.2	22.3		4.6	2.5	6.1	7.2	44.0
16-2	R	6.6			129.1	19.6	1.4	5.5	1.5	
16-3	W	7.4	224.1	8.2		2.2	0.9	1.1	1.1	54.0
16-3	R	7.7			124.5	18.7	0.3	3.9	1.0	
16-4	W	6.9	138.0	2.2		0.9	1.4	0.3	0.4	30.0
16-4	R	5.9			79.7	7.0	0.3	1.5	0.5	
16-5	W	6.4	60.0	0.7		0.3	0.8	0.1	0.1	27.0
16-5	R	5.3			50.6	3.6	0.3	1.7	0.4	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
16-2	2.0	516.5	48.0	13.5	341.0	9.0	115.0	105.0	4.5
16-3	1.0	514.0	48.0	10.5	372.0	3.5	122.0	75.0	3.0
16-4	1.0	507.0	16.0	10.0	327.0	1.5	194.0	55.0	1.5
16-5	0.5	512.0	4.0	8.5	333.0	1.5	203.0	105.0	1.5

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
17-2	3-0	0.85	44.7	30.2	14.5	0.3			
17-3	0-70	1.06	26.9	11.3	15.5	11.3	71.5	13.1	15.3
17-4	70-76	1.16	16.0	7.8	8.2	0.5	76.4	8.4	15.1
17-5		1.32	10.0	6.3	3.7		81.3	3.4	15.1

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
17-2	W	7.6	310.3	10.8		2.4	3.7	3.4	5.7	94.0
17-2	R	6.0			118.7	14.8	1.5	4.5	1.4	
17-3	W	7.0	103.4	4.1		0.7	1.0	0.7	0.3	70.0
17-3	R	7.1			90.9	12.6	0.2	3.0	0.5	
17-4	W	6.2	52.0	2.4		0.2	0.9	0.1	0.1	45.0
17-4	R	4.9			41.7	4.4	0.4	1.5	0.4	
17-5	W	6.3	52.0	0.4		0.3	0.9	0.0	0.1	30.0
17-5	R	4.8			10.2	3.0	0.3	1.0	0.3	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
17-2	1.5	515.0	49.0	13.0	478.0	7.0	213.0	105.0	3.5
17-3	0.5	513.0	46.5	11.0	485.5	2.5	214.0	70.0	2.0
17-4	0.5	511.0	12.0	11.0	394.5	1.5	202.0	35.0	2.0
17-5	0.5	506.5	7.0	8.0	341.5	1.0	193.0	40.0	2.5

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
18-2	1-0	0.65	59.1	45.7	13.4	0.0			
18-3	0-11	0.68	46.5	23.6	22.9	1.7	65.4	14.7	19.8
18-4	11-47	1.07	12.1	8.3	3.7	1.8	76.2	8.5	15.2

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
18-2	W	8.0	655.2	17.6		8.6	2.5	8.6	6.9	52.0
18-2	R	6.7			154.2	22.0	1.0	5.4	1.3	
18-3	W	7.6	396.6	10.3		5.5	1.2	2.5	1.2	46.0
18-3	R	7.2			124.1	24.0	0.5	4.4	1.0	
18-4	W	7.2	164.0	1.2		2.0	0.8	0.6	0.2	10.0
18-4	R	6.6			19.3	9.4	0.3	2.1	0.6	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
18-2	2.0	870.5	26.4	7.5	214.5	7.5	44.5	102.0	11.0
18-3	1.0	696.5	14.1	6.5	232.5	6.0	76.0	79.5	8.0
18-4	0.5	245.5	2.7	4.5	42.5	1.5	41.5	35.5	4.0

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
19-2	2-0	0.7	46.5	37.6	8.8	0.1			
19-3	0-9	0.75	35.4	21.9	13.5	0.9	70.6	12.1	17.2
19-4	9-56	1.15	15.6	8.8	6.8	3.5	74.2	5.0	20.7

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
19-2	W	8.0	586.2	6.1		6.2	3.9	6.9	7.0	55.0
19-2	R	7.0			105.6	18.4	0.8	4.7	1.2	
19-3	W	7.6	379.3	7.5		5.0	0.9	1.1	1.4	47.0
19-3	R	7.3			90.0	22.8	0.1	4.2	1.0	
19-4	W	7.3	190.0	0.6		1.9	0.8	0.6	0.3	23.0
19-4	R	6.7			26.3	11.5	0.3	2.4	0.6	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
19-2	1.5	617.5	21.5	6.0	154.5	7.0	35.5	73.5	7.5
19-3	1.0	572.0	19.9	6.0	144.5	5.0	34.5	63.5	6.5
19-4	1.5	84.5	3.5	4.0	40.5	2.0	6.5	37.0	8.0

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
20-2	2-0	0.55	39.8	25.7	14.0	0.1			
20-3	0-12	0.59	43.9	22.7	21.2	1.4	54.1	24.2	21.6
20-4	12-39	1.06	18.7	8.7	10.0	2.6	56.5	20.2	23.2

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
20-2	W	8.1	568.9	4.1		6.8	3.0	5.6	7.2	26.0
20-2	R	7.1			174.3	19.6	0.7	3.7	1.1	
20-3	W	7.8	431.0	4.8		4.6	0.8	1.1	1.6	21.0
20-3	R	7.3			84.7	40.4	0.1	3.7	1.0	
20-4	W	7.4	190.0	0.8		2.0	0.6	0.5	0.0	4.0
20-4	R	6.7			79.3	12.7	0.4	2.1	0.9	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
20-2	1.5	308.0	15.4	5.0	108.0	5.5	12.5	65.5	8.0
20-3	2.0	174.5	19.8	5.0	90.5	2.5	9.5	70.5	7.5
20-4	2.0	5 4.0	3.2	4.5	51.5	1.0	8.0	37.0	8.0

I

P H	RD	BD	% water by weight				%		
			1/3	15	1/3-15	AWC	Sand	Silt	Clay
21-2	2-0	0.65	59.5	42.0	17.5	0.2			
21-3	0-51	0.68	31.3	14.1	17.1	5.9	73.6	11.9	14.4
21-4	51-59	1.16	15.7	9.1	6.6	0.6	75.2	5.0	19.7

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
21-2	W	8.2	706.9	33.2		7.4	3.5	7.2	8.2	60.0
21-2	R	6.8			135.6	23.2	1.0	4.8	1.4	
21-3	W	7.4	137.9	11.3		1.2	1.3	0.8	0.4	78.0
21-3	R	7.2			88.7	16.4	0.2	2.9	0.7	
21-4	W	7.1	233.0	0.7		0.3	0.8	0.2	0.2	23.0
21-4	R	6.2			36.3	5.9	0.4	2.4	0.6	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
21-2	1.5	860.5	19.9	8.0	213.5	8.5	36.0	108.5	10.0
21-3	0.5	734.0	11.2	7.5	304.0	3.0	116.0	87.0	5.0
21-4	0.5	632.5	1.5	7.0	284.0	2.5	169.5	127.5	4.0

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
22-2	2-0	0.65	62.2	44.7	17.5	0.2			
22-3	0-55	0.97	24.0	14.7	9.3	5.0	73.8	9.3	16.8
22-4	55-62	1.22	14.6	9.2	53.1	0.4	73.1	6.1	20.7

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
22-2	W	7.6	310.3	19.0		17.0	3.4	8.2	8.3	67.0
22-2	R	6.0			142.1	20.2	2.1	4.7	1.4	
22-3	W	7.4	172.4	6.8		1.8	1.0	0.7	0.7	72.0
22-3	R	7.2			72.8	15.5	0.1	2.8	1.0	
22-4	W	6.5	78.0	0.1		0.2	0.9	0.2	0.2	17.0
22-4	R	6.0			61.0	6.2	0.4	2.1	0.8	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
22-2	1.5	992.0	15.7	9.0	424.5	8.0	167.5	104.0	11.5
22-3	0.5	735.5	10.9	7.5	200.5	2.5	96.5	60.0	4.0
22-4	0.5	710.5	1.9	8.5	193.0	2.0	103.5	63.0	3.0

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
23-2	3-0	0.55	59.2	45.1	14.1	0.2			
23-3	0-65	0.84	29.3	14.8	14.4	7.8	70.9	10.3	18.7
23-4		1.18	15.1	10.1	4.9		73.1	6.1	20.7

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
23-2	W	7.7	689.6	20.3		8.2	3.6	8.0	9.1	56.0
23-2	R	7.4			131.7	25.0	1.0	5.2	1.5	
23-3	W	7.3	172.4	4.8		1.2	0.9	0.7	0.7	72.0
23-3	R	7.3			90.8	15.5	0.1	3.2	1.3	
23-4	W	6.4	86.0	0.3		0.1	0.8	0.1	0.4	27.0
23-4	R	6.2			84.1	6.3	0.3	2.2	1.0	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
23-2	1.5	723.5	12.0	7.0	162.5	8.0	17.5	107.0	11.0
23-3	0.5	842.5	12.4	8.0	244.0	2.0	94.5	91.5	5.5
23-4	0.5	807.0	2.2	9.5	237.0	2.5	248.0	92.0	4.5

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
24-2	2-0	0.65	64.1	54.5	9.5	0.1			
24-3	0-36	0.85	32.5	17.0	15.4	4.7	62.2	16.3	21.4
24-4	36-44	1.17	23.1	14.3	8.7	0.8	63.8	7.6	28.4

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
24-2	W	8.0	500.0	16.9		4.9	4.2	6.6	6.8	58.0
24-2	R	6.5			167.6	30.3	1.3	7.1	2.0	
24-3	W	7.2	120.7	3.8		1.1	0.9	0.6	0.4	78.0
24-3	R	7.1			152.6	15.7	0.1	3.7	0.9	
24-4	W	6.1	69.0	0.7		0.1	0.9	0.1	0.2	32.0
24-4	R	5.1			85.4	7.4	0.3	3.7	0.5	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
24-2	1.5	579.5	31.1	9.0	321.5	7.5	69.5	107.0	10.5
24-3	0.5	726.5	13.4	10.0	374.5	2.0	182.5	74.5	6.0
24-4	0.5	808.5	1.8	13.0	224.5	2.5	170.0	150.5	4.5

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
25-2	3-0	0.55	74.9	62.5	12.3	0.2			
25-3	0-30	0.59	42.8	18.0	24.7	4.3	57.8	22.3	19.7
25-4	30-52	1.13	23.3	12.5	10.7	2.6	58.4	16.1	25.4

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
25-2	W	8.1	655.2	23.0		17.8	2.3	7.7	8.1	76.0
25-2	R	6.5			167.6	25.2	0.6	4.9	1.5	
25-3	W	7.6	344.8	7.5		5.1	1.6	1.7	1.0	79.0
25-3	R	7.2			152.6	22.9	0.1	3.2	1.6	
25-4	W	6.5	78.0	0.9		0.3	0.6	0.3	0.2	55.0
25-4	R	6.0			40.8	7.6	0.4	2.8	0.9	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
25-2	1.5	837.5	48.1	7.0	217.0	8.0	39.0	80.0	11.5
25-3	1.0	956.0	19.6	7.0	248.0	2.5	79.5	106.5	6.0
25-4	0.5	758.0	7.7	11.0	271.0	2.5	128.0	87.5	5.0

I

				% water by weight				%		
P	H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
26-2		3-0	0.7	63.7	55.1	8.6	0.1			
26-3		0-30	0.78	33.2	21.3	11.9	2.7	53.6	23.0	23.2
26-4		30-43	1.00	23.1	13.5	9.5	1.2	59.8	15.2	24.9

II

P	H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
26-2		W	8.3	672.4	19.6		8.5	2.5	8.6	10.7	70.0
26-2		R	7.0			188.4	26.0	1.2	5.7	2.0	
26-3		W	7.6	344.8	11.6		4.5	1.1	1.6	1.6	73.0
26-3		R	7.3			135.6	24.7	0.1	3.9	2.1	
26-4		W	6.5	121.0	0.9		0.4	0.9	0.2	0.5	54.0
26-4		R	6.2			73.0	8.6	0.3	2.3	1.3	

III

P	H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
26-2		1.5	839.5	15.6	7.5	206.5	7.5	31.5	96.5	11.0
26-3		1.0	983.0	15.4	7.5	296.5	3.0	80.5	114.5	7.5
26-4		0.5	971.0	6.9	13.0	344.0	3.0	174.0	134.5	6.0

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
27-2	.5-0	0.80	82.2	66.3	15.9	0.0			
27-3	0-11	0.78	43.2	27.8	15.3	1.3	48.5	22.1	29.4
27-4	11-27	1.35	14.1	7.9	6.1	2.6	38.9	37.1	24.0

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
27-2	W	8.1	1380	30.7		9.2	5.4	9.5	9.3	31.0
27-2	R	6.5			220.4	19.9	1.0	4.7	1.6	
27-3	W	7.8	741	10.8		2.1	3.2	2.3	2.8	5.0
27-3	R	6.7			112.1	20.1	0.4	4.4	1.3	
27-4	W	7.8	310	0.6		1.3	3.1	1.5	1.3	2.0
27-4	R	7.0			24.2	14.0	0.5	3.2	0.6	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
27-2	2.1	1057.0	55.8	11.0	402.0	13.0	20.0	107.0	4.5
27-3	1.0	734.5	49.7	9.5	171.5	1.5	13.0	76.0	3.0
27-4	0.9	81.5	9.4	8.0	58.0	1.5	8.0	56.0	2.0

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
28-2	.5-0	0.70	88.9	61.7	27.2	0.1			
28-3	0-20	0.72	49.4	29.8	19.6	2.8	41.7	28.9	29.4
28-4	20-21	0.95	14.7	10.7	3.9	0.7	72.3	7.7	20.0

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
28-2	W	8.1	1380	32.6		15.2	5.4	12.8	13.1	39.0
28-2	R	6.7			280.0	19.9	0.9	4.4	1.7	
28-3	W	7.8	741	6.5		2.1	3.6	2.2	3.1	4.0
28-3	R	6.8			111.5	18.7	0.7	3.6	1.4	
28-4	W	7.7	293	0.7		1.0	3.4	1.4	5.9	2.0
28-4	R	6.8			26.2	9.0	1.0	1.6	0.7	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
28-2	0.1	968.5	46.3	10.5	405.5	2.0	6.0	108.0	1.0
28-3	1.2	897.5	36.6	11.0	169.0	3.0	15.0	92.0	4.0
28-4	0.8	147.0	8.7	6.0	88.0	2.5	24.0	218.0	1.5

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
29-2	2-0	0.85	46.0	24.3	21.7	0.3			
29-3	0-17	1.11	32.0	19.4	12.5	2.3	57.0	16.2	26.8
29-4	17-20	1.23	19.8	12.5	7.3	1.7	67.5	12.0	21.5

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
29-2	W	8.1	860	11.7		8.8	5.6	7.7	7.7	6.0
29-2	R	6.8			110.4	14.7	1.4	3.2	1.4	
29-3	W	7.8	586	8.6		2.1	3.2	2.2	2.9	2.0
29-3	R	6.8			55.2	12.1	0.7	4.3	1.0	
29-4	W	7.7	362	2.2		1.5	3.3	1.7	1.6	2.0
29-4	R	6.8			42.2	10.0	1.4	2.2	0.8	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
29-2	0.1	669.5	28.5	10.5	199.5	3.5	7.0	78.0	3.0
29-3	1.1	400.5	21.4	8.0	118.0	3.0	11.0	62.0	2.5
29-4	1.0	207.5	14.1	6.0	113.5	1.0	7.0	52.0	2.5

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
30-2	1-0	0.80	49.1	31.9	17.2	0.1			
30-3	0-15	0.97	31.4	20.8	10.5	1.5	72.3	8.5	19.2
30-4	15-17	1.23	11.8	6.7	5.1	1.0	70.1	8.4	21.5

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
30-2	W	8.0	860	11.1		8.2	4.2	7.0	13.1	10.0
30-2	R	6.9			143.0	17.5	0.6	3.7	1.5	
30-3	W	7.8	638	9.8		1.9	3.0	1.7	2.0	3.0
30-3	R	6.8			71.0	12.4	0.5	3.3	1.0	
30-4	W	7.6	224	0.6		1.1	2.9	1.3	1.0	2.0
30-4	R	7.0			17.6	7.5	0.5	2.8	0.5	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
30-2	0.4	814.5	32.3	9.5	176.0	7.0	8.0	75.0	3.5
30-3	0.8	622.5	25.7	9.0	143.0	4.0	15.0	69.0	3.0
30-4	0.9	146.0	9.1	7.5	86.5	1.5	8.0	55.0	1.5

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
31-2	1-0	0.75	61.3	45.3	16.0	0.1			
31-3	0-51	0.80	27.9	16.7	11.2	4.5	64.6	11.1	24.3
31-4	51-65	1.14	17.9	10.9	7.0	1.1	72.4	7.0	21.6
31-5	65-72	1.17	12.9	8.3	4.5	0.3	75.1	6.0	18.9

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
31-2	W	8.0	690	28.9		11.4	4.2	9.0	11.3	43.0
31-2	R	6.3			151.7	19.1	0.8	5.6	1.4	
31-3	W	7.0	207	6.5		0.9	3.6	1.5	0.7	42.0
31-3	R	5.9			69.3	8.1	0.7	2.9	0.6	
31-4	W	7.0	103	0.6		0.2	3.3	0.4	0.2	3.0
31-4	R	5.9			33.7	4.6	1.2	2.5	0.3	
31-5	W	7.5	207	0.4		0.8	3.9	1.6	0.3	2.0
31-5	R	6.4			27.2	5.1	0.9	1.9	0.2	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
31-2	1.1	2003.5	42.8	11.5	343.5	8.5	35.0	135.0	3.5
31-3	0.3	967.5	35.8	11.0	439.0	3.5	83.0	108.0	2.0
31-4	0.0	763.0	9.0	12.0	657.0	2.0	308.0	2509.0	3.0
31-5	0.2	431.5	6.5	8.5	421.5	1.0	120.0	1023.0	2.5

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
32-2	1-0	0.75	69.2	51.1	18.1	0.1			
32-3	0-36	0.72	29.8	17.6	12.1	3.1	62.0	13.7	24.3
32-4	36-49	1.01	19.5	12.3	7.1	0.9	67.5	5.9	26.6

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
32-2	W	8.2	1030	27.7		7.8	4.0	8.1	11.2	38.0
32-2	R	6.7			255.6	22.8	1.4	5.8	1.8	
32-3	W	7.4	310	1.5		0.9	4.6	1.4	2.0	28.0
32-3	R	6.2			60.2	8.5	0.4	2.5	1.4	
32-4	W	6.9	155	0.6		0.2	4.0	0.3	0.7	15.0
32-4	R	5.7			15.9	5.0	0.8	2.1	0.7	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
32-2	1.8	1319.0	52.0	11.0	297.0	5.5	21.0	142.0	2.0
32-3	0.4	963.0	38.5	11.0	341.0	3.0	68.0	136.0	2.5
32-4	0.3	1024.5	6.1	14.0	349.5	2.0	124.0	335.0	2.0

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
33-2	.5-0	0.70	62.9	41.7	21.2	0.0			
33-3	0-17	0.85	37.3	20.8	16.5	2.3	54.4	18.8	26.8
33-4	17-47	0.85	23.2	13.7	9.5	2.4	65.0	8.4	26.6

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
33-2	W	8.2	1210	24.0		7.6	4.0	8.3	7.7	43.0
33-2	R	6.7			252.1	21.2	0.5	5.7	1.7	
33-3	W	7.5	397	7.4		1.0	4.3	1.6	2.0	13.0
33-3	R	6.3			78.9	9.8	0.3	3.2	1.4	
33-4	W	6.8	138	0.8		0.2	3.5	0.3	1.4	9.0
33-4	R	5.9			51.8	5.3	0.2	2.5	1.0	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
33-2	1.0	1441.5	65.1	11.5	267.0	13.5	18.0	82.0	3.5
33-3	0.5	1039.5	38.2	11.0	337.0	3.0	63.0	111.0	3.0
33-4	0.0	757.0	9.1	14.5	639.5	3.0	445.0	3916.0	2.5

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
34-2	4-0	0.60	65.1	37.5	27.5	0.6			
34-3	0-63	0.86	27.3	15.3	11.9	6.5	59.6	15.3	25.1
34-4	63-68	1.10	17.1	10.9	6.2	0.3	65.1	7.5	27.4

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
34-2	W	8.2	1210	27.1		15.5	4.8	8.5	11.3	40.0
34-2	R	6.4			266.0	21.4	0.6	4.5	1.7	
34-3	W	7.1	241	4.3		0.7	3.9	0.7	2.8	38.0
34-3	R	6.1			60.0	12.7	0.3	2.3	1.2	
34-4	W	6.8	103	0.5		0.2	3.4	0.2	0.6	13.0
34-4	R	6.0			56.5	5.1	0.4	1.7	0.7	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
34-2	1.3	1359.5	60.3	11.0	419.0	11.5	12.0	119.0	2.0
34-3	0.3	1136.5	36.7	11.0	326.5	1.5	56.0	95.0	2.0
34-4	0.0	748.0	12.2	11.5	570.5	1.0	282.0	2784.0	1.5

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
35-2	1-0	0.65	72.4	51.4	20.9	0.1			
35-3	0-42	0.89	31.3	18.3	12.9	4.8	59.6	15.3	25.1
35-4	42-51	1.22	23.2	15.3	7.9	0.8	65.1	7.5	27.4

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
35-2	W	8.2	1030	25.8		15.7	5.7	9.0	11.7	26.0
35-2	R	6.7			264.3	21.2	0.5	5.5	1.7	
35-3	W	6.9	207	4.6		0.6	3.5	0.9	1.8	22.0
35-3	R	5.7			75.4	8.5	0.4	3.4	1.1	
35-4	W	6.7	121	0.5		0.1	3.1	0.2	0.7	10.0
35-4	R	5.7			50.0	6.2	0.6	2.8	1.0	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
35-2	2.1	1078.0	50.4	11.0	303.5	8.5	22.0	143.0	2.5
35-3	0.4	867.5	23.5	11.0	390.5	1.5	111.0	311.0	0.2
35-4	0.3	769.0	5.6	11.5	340.5	3.0	139.0	277.0	3.0

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
36-2	1-0	0.70	66.2	46.3	19.9	0.1			
36-3	0-28	0.85	29.7	15.5	14.2	3.3	61.8	15.7	22.5
36-4	28-32	1.13	19.8	10.6	9.1	1.4	67.6	10.1	22.3

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
36-2	W	8.2	860	22.7		13.9	5.9	7.9	7.8	42.0
36-2	R	6.1			156.0	15.0	0.9	4.8	1.5	
36-3	W	6.9	190	4.9		0.7	3.0	0.9	1.0	37.0
36-3	R	5.6			56.5	7.2	0.3	2.3	0.8	
36-4	W	6.5	103	0.7		0.2	2.8	0.3	0.9	33.0
36-4	R	5.5			48.2	3.8	0.4	1.8	0.7	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
36-2	1.8	1492.5	85.8	12.0	530.5	6.0	34.0	140.0	3.5
36-3	0.5	1027.0	28.5	11.5	401.5	3.5	113.0	195.0	2.0
36-4	0.0	588.0	9.9	11.0	771.5	1.5	574.0	3692.0	1.5

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
37-2	.5-0	0.75	66.4	27.2	39.1	0.4			
37-3	0-26	0.68	34.7	20.9	13.8	2.3	51.9	17.9	30.2
37-4	26-48	1.07	26.7	13.6	13.0	2.9	54.9	15.2	29.9

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
37-2	W	8.4	1380	20.9		8.5	4.1	8.8	11.3	33.0
37-2	R	6.8			221.0	16.7	0.6	6.4	2.2	
37-3	W	7.7	500	2.2		2.0	3.7	2.7	0.6	30.0
37-3	R	6.6			78.0	11.4	0.7	3.6	1.5	
37-4	W	7.7	328	1.7		1.2	3.6	1.6	2.5	30.0
37-4	R	6.8			62.1	9.2	0.5	2.4	0.9	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
37-2	1.6	1136.0	76.0	11.0	289.5	8.5	16.0	120.0	2.5
37-3	0.6	664.0	32.6	10.0	228.0	2.5	26.0	102.0	2.5
37-4	0.6	326.0	4.3	13.0	126.0	2.0	25.0	103.0	3.0

I

P H	RD	BD	% water by weight				%		
			1/3	15	1/3-15	AWC	Sand	Silt	Clay
38-2	.5-0	0.75	63.3	63.2	0.1	0.0			
38-3	0-52	0.58	22.5	12.7	9.8	2.9	67.2	10.3	22.5
38-4	52-59	1.19	12.7	7.4	5.3	0.4	73.4	9.5	18.1

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
38-2	W	8.3	1030	22.1		14.1	4.8	8.4	7.9	21.0
38-2	R	6.3			161.7	12.7	0.6	6.7	1.7	
38-3	W	6.5	137	4.6		0.3	3.1	0.6	0.6	19.0
38-3	R	5.3			45.6	5.7	0.4	2.4	0.7	
38-4	W	6.5	86	1.5		0.2	2.7	0.2	0.4	17.0
38-4	R	5.5			7.3	2.4	0.3	1.4	0.4	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
38-2	2.1	1173.5	33.2	12.0	300.5	12.0	41.0	168.0	4.5
38-3	0.5	643.5	25.2	9.5	433.5	1.0	188.0	127.0	2.0
38-4	0.0	558.0	7.5	11.0	557.0	0.5	368.0	3542.0	1.0

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
39-2	1-0	0.75	80.1	49.9	30.2	0.2			
39-3	0-63	0.90	28.4	14.4	14.0	7.8	65.5	13.6	20.9
39-4	63-70	1.21	14.3	8.2	6.1	0.5	75.9	6.0	18.1

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
39-2	W	8.2	860	29.5		16.3	4.7	8.8	8.4	26.0
39-2	R	6.3			188.2	14.1	0.8	5.6	1.4	
39-3	W	6.8	155	2.8		0.7	3.2	0.9	0.8	23.0
39-3	R	5.6			71.0	6.7	0.3	3.4	0.9	
39-4	W	6.6	138	0.8		0.3	2.7	0.3	0.4	22.0
39-4	R	5.2			6.9	2.5	1.1	1.8	0.3	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
39-2	2.4	1236.0	41.1	11.0	374.5	7.5	18.0	185.0	3.5
39-3	0.4	772.5	33.1	11.5	432.0	2.5	138.0	114.0	2.0
39-4	0.6	536.5	7.1	9.0	382.5	2.0	205.0	623.0	4.5

I

			% water by weight				%		
P H	RD	BD	1/3	15	1/3-15	AWC	Sand	Silt	Clay
40-2	1-0	0.75	79.1	42.4	36.6	0.2			
40-3	0-64	0.78	26.2	12.8	13.4	6.6	66.4	11.1	22.5
40-4	64-68	1.22	15.6	7.9	7.7	0.3	74.3	7.6	18.1

II

P H	D	pH	Cond.	%OM	CEC	Ca	Na	Mg	K	P
40-2	W	8.2	1030	27.7		14.1	5.6	10.4	9.6	26.0
40-2	R	6.7			168.2	16.0	1.1	5.4	1.4	
40-3	W	6.7	172	4.3		0.6	2.8	0.7	0.7	22.0
40-3	R	5.6			68.2	5.7	0.5	2.4	0.6	
40-4	W	6.6	103	0.5		0.2	4.0	0.4	0.5	19.0
40-4	R	5.3			34.7	3.0	0.4	1.6	0.5	

III

P H	Sr	Mn	Zn	Ni	Fe	Pb	Al	Si	Cu
40-2	1.6	953.5	41.0	10.0	316.0	7.5	14.0	119.0	4.0
40-3	0.4	826.5	33.9	10.5	401.0	2.0	99.0	137.0	2.5
40-4	1.2	534.0	8.3	7.5	383.0	1.0	96.0	701.0	2.0

LITERATURE CITED

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Arnold, H. V. 1916. The Early History of Inkster. H. V. Arnold, Larimore, North Dakota. 128 p.

Attiwill, P. M. 1966. The chemical composition of rain water in relation to cycling of nutrients in mature Eucalyptus forest. Plant and Soil 24: 390-406.

Ayyad, M. A. G. and R. L. Dix. 1964. An analysis of a vegetation-microenvironmental complex on prairie slopes in Saskatchewan. Ecol. Monogr. 34: 421-442.

Bakuzis, E. V. 1959. Synecological coordinates in forest classification and in reproduction studies. Ph.D. Thesis. Univ. of Minnesota, St. Paul, Minn.

Barkham, J. P. and J. W. Norris. 1970. Multivariate procedures in an investigation of vegetation and soil relations of two beech woodlands, Cotswald Hills, England. Ecology 51: 631-639.

Beals, E. W. 1960. Forest bird communities in the Apostle Islands of Wisconsin. Wilson Bull. 72: 156-181.

Becking, R. W. 1957. The Zurich-Montpellier School of phytosociology. Bot. Rev. 23: 411-488.

______. 1968. Vegetational response to changes in environment and changes in species tolerance with time. Vegetation 16: 135-158.

Bormann, F. H., T. G. Siccama, G. E. Likens, and R. H. Whittaker. 1970. The Hubbard Brook ecosystem study: composition and dynamics of the tree stratum. Ecol. Monogr. 40: 373-388.

Bouyoucos, G. J. 1951. A recalibration of the hydrometer method for making mechanical analysis of soils. Agron. J. 43: 434-438.

Braun-Blanquet, J. 1932. Plant Sociology (translated by G. D. Fuller and H. S. Conrad). McGraw Hill Book Co., New York. 439 p.

______. 1964. Pflanzensociologie: Grundzuge der Vegetationskunde. 3te aufl. Springer Verlag, Wein. 865 p.

Bray, J. R. and J. T. Curtis. 1957. An ordination of the upland forest communities of southern Wisconsin. Ecol. Monogr. 27: 325-349.

Bray, J. R. and E. Gorham. 1964. Litter production in forests of the world. Adv. Ecol. Res. 2: 101-157.

Buell, M. F. and V. Facey. 1960. Forest-prairie transition west of Itasca Park, Minnesota. Bull. of the Torrey Bot. Club 87: 46-58.

Carlisle, A., A. H. F. Brown, and E. J. White. 1965. The interception of precipitation by oak (Quercus petraea) on a high rainfall site. Quart. J. Forestry 59: 140-143.

______. 1966. The organic matter and nutrient elements in the precipitation beneath a sessile oak (Quercus petraea) canopy. J. Ecol. 54: 87-98.

______. 1967. Nutrient content of tree stem flow and ground flora litter and leachates in a sessile oak (Quercus petraea) woodland. J. Ecol. 55: 615-627.

Clayton, J. S. 1968. Report on international soil correlation. Unpublished.

Clayton, L. 1972. Personal communication.

Clements, J. R. 1971. Evaluating summer rainfall through a multilayered largetooth aspen community. Can. J. Forest Res. 1: 20-31.

Cole, D. W., S. P. Gessel and S. F. Dice. 1967. Distribution and cycling of nitrogen, phosphorus, potassium and calcium in a second-growth Douglas-fir ecosystem. p. 197-232. In H.E. Young (ed.) Symposium on Primary Production and Mineral Cycling in Natural Ecosystems. Orono, Maine.

Cooley, W. W. and P. R. Lohnes. 1962. Multivariate Procedures for the Behavioral Sciences. Wiley, New York. 211 p.

Crum, H., W. C. Steere, and L. Anderson. 1965. A list of the mosses of North America. The Bryol. 68: 377-432.

Curtis, J. T. and R. P. McIntosh. 1951. An upland forest continuum in the prairie forest border region of Wisconsin. Ecology 31: 434-455.

Curtis, J. T. 1959. The Vegetation of Wisconsin. University of Wisconsin Press, Madison. 657 p.

Daubenmire, R. 1966. Vegetation: identification of typal communities. Science 151: 291-298.

Erman, D. C. and W. T. Helm. 1971. Comparison of some species importance values and ordination techniques used to analyse benthic invertebrate communities. Oikos 22: 240-247.

Facey, V. 1972. Personal communication.

Fernald, M. L. 1950. Gray's Manual of Botany. 8th ed. American Book Co., New York. 1632 p.

Frank, E. C. and R. Lee. 1966. Potential solar beam irradiation on slopes: Tables for 30° to 50° latitude. Rocky Mountain Forest and Range Exp. Sta., U. S. Forest Service Res. Paper RM-18. 116 p.

Franke, W. 1967. Mechanisms of foliar penetration of solutions. Ann. Rev. Plant Physiol. 18: 281-300.

Geiger, R. 1965. The Climate Near the Ground. 4th ed. Harvard Univ. Press, Boston, Mass. 611 p.

Gersper, P. L. and N. Holowaychuk. 1971. Some effects of stem flow from forest canopy trees on chemical properties of soil. Ecology 52: 692-702.

Greenland, D. J. and J. M. L. Kowal. 1960. Nutrient content of the moist tropical forests of Ghana. Plant and Soil 12: 154-174.

Greig-Smith, P. 1964. Quantitative Plant Ecology. 2nd ed. Butterworths, London. 256 p.

Grigal, D. F. and H. F. Arneman. 1970. Quantitative relations among vegetation and soil classifications from northeastern Minnesota. Can. J. Bot. 48: 555-566.

Haase, E. F. 1970. Environmental fluctuations on south-facing slopes in the Santa Catalina Mountains of Arizona. Ecology 51: 959-974.

Hale, M. E. Jr. and W. L. Culberson. 1965. A third checklist of the lichens of the continental United States and Canada. The Bryol. 69: 141-182.

Hansen, D. E. and J. Kume. 1970. Geology and Ground Water Resources of Grand Forks County. Part I. Geology. North Dakota Geology Survey Bull. 53, 76 p.

Helvey, J. D. and J. H. Patric. 1965. Canopy and litter interception of rainfall by hardwoods of the eastern United States. Water Resour. Res. 1: 193-206.

Hughes, M. K. 1971. Tree biocontent, net production and litter fall in a deciduous woodland. Oikos 22: 62-73.

Jackson, M. L. 1958. Soil Chemical Analysis. Prentice Hall, Inc., Englewood Cliffs, N. J. 498 p.

Jeglum, J. K., C. F. Wehrhahn, and J. M. A. Swan. 1971. Comparisons of environmental ordinations with principal component vegetational ordinations for sets of data having different degrees of complexity. Can. J. Forest Res. 1: 99-112.

Johnson, W. C. 1971. The forest overstory vegetation of the Missouri River floodplain in North Dakota. Ph.D. Thesis. North Dakota State Univ., Fargo, North Dakota.

Keammerer, W. R. 1972. The understory vegetation of the bottomland forests of the Missouri River in North Dakota. Ph.D. Thesis. North Dakota State Univ., Fargo, North Dakota.

Kelly, T. E. and Q. F. Paulson. 1970. Geology and Ground Water Resources of Grand Forks County. Part III. Ground Water Resources. North Dakota Geological Survey Bull. 53, 58 p.

Kine, J. R. 1969. Soil chemistry as a factor in the function of grassland ecosystems. p. 71-88. <u>In</u> R. L. Dix and R. G. Beidleman (eds.) The Grassland Ecosystem: A Preliminary Synthesis. Fort Collins, Colorado.

Kittredge, J. 1948. Forest Influences. McGraw-Hill Co., New York. 281 p.

Kuchler, A. W. 1964. Potential natural vegetation of the conterminous United States. American Geographical Society Special Publication No. 36, New York. Map (39 x 60 inches) plus Manual. 150 p.

Leyton, L. 1958. The mineral requirements of forest plants. p. 1026-1039. <u>In</u> W. Ruhland (ed.) Handbuch der Pflanzenphysiologie. Band IV. Springer-Verlag, Berlin.

Likens, G. E., F. H. Bormann, N. M. Johnson, and R. S. Pierce. 1967. The Ca, Mg, K, and Na budgets for a small forested ecosystem. Ecology 48: 772-785.

Likens, G. E. and J. S. Eaton. 1970. A polyurethane stemflow collector for trees and shrubs. Ecology 51: 938-939.

Loucks, O. L. 1962. Ordinating forest communities by means of environmental scalars and phytosociological indices. Ecol. Monogr. 32: 137-166.

McClelland, J. E., C. A. Mogen, W. M. Johnson, F. W. Schroer, and J. S. Allen. 1959. Chernozems and associated soils of eastern North Dakota: some properties and topographic relationships. Soil Sci. Soc. Amer. Proc. 23: 51-56.

McColl, J. G. 1970. Properties of some natural waters in a tropical wet forest of Costa Rica. Bioscience 20: 1096-1100.

Mowbray, T. B. and H. J. Oosting. 1968. Vegetation gradients in relation to environment and phenology in a southern Blue Ridge gorge. Ecol. Monogr. 38: 309-344.

National Soil Survey Committee of Canada. 1965. Report on the Sixth Meeting of the National Soil Survey Committee of Canada. Laval Univ., Quebec. 132 p.

Nelson, P. W. 1964. The forests of the lower Sheyene Valley, North Dakota. M.S. Thesis. North Dakota State Univ., Fargo, North Dakota.

Nihlgard, B. 1970. Precipitation, its chemical composition and effect on soil water in a beech and spruce forest in southern Sweden. Oikos 21: 208-217.

_______. 1972. Plant biomass production and distribution of chemical elements in a beech and a planted spruce forest in south Sweden. Oikos 23: 69-81.

Norman, C. D. 1966. Effects of beavers on river valley forests in eastern North Dakota. Unpublished.

Nye, P. H. 1961. Organic matter and nutrient cycles under moist tropical forest. Plant and Soil 13: 333-346.

Omodt, H. W., G. A. Johnsgard, D. D. Patterson and O.P. Olson. 1968. The Major Soils of North Dakota. Agricultural Experimental Station Bull. No. 472. North Dakota State Univ., Fargo. Map (23 x 25 inches) plus manual. 60 p.

Original Land Survey. 1880. North Dakota State Water Bureau, Bismarck, North Dakota.

Orloci, L. 1966. Geometric models in ecology. 1. The theory and application of some ordination methods. J. Ecol. 54: 193-215.

Ovington, J. D. 1962. Quantitative ecology and the woodland ecosystem concept. Adv. Ecol. Res. 1: 103-192.

Partch, M. L. 1949. Habitat studies of soil moisture in relation to plants and plant communities. Ph.D. Dissertation. Univ. of Wisconsin, Madison.

Peek, J. M. 1970. Relation of canopy area and volume to production of three woody species. Ecology 51: 1098-1101.

Perkin-Elmer Corporation. 1971. Analytical Methods for Atomic Absorption Spectrophotometry. Perkin-Elmer Corp., Norwalk, Conn.

Reiners, W. A. and N. M. Reiners. 1970. Energy and nutrient dynamics of forest floors in three Minnesota forests. J. Ecol. 58: 497-519.

Reiners, W. A. 1972. Nutrient content of canopy throughfall in three Minnesota forests. Oikos 23: 14-22.

Richards, L. A. (ed.). 1954. Diagnosis and Improvement of Saline and Alkali Soils. U. S. Department of Agriculture. Handbook No. 60. Washington, D. C. 160 p.

Rodin, L. E. and N. I. Bazilevich. 1967. Production and Mineral Cycling in Terrestrial Vegetation. Oliver and Boyd, Edinburg and London. 288 p.

Rudd, V. E. 1951. Geographical affinities of the flora of North Dakota. Amer. Midl. Nat. 45: 722-739.

Schofield, R. K. and A. W. Taylor. 1955. The measurement of pH. Soil Sci. Soc. Amer. Proc. 19: 164-167.

Siccama, T. G., F. H. Bormann, and G. E. Likens. 1970. The Hubbard Brook ecosystem study: productivity nutrients and phytosociology of the herbaceous layer. Ecol. Monogr. 40: 389-402.

Stanhill, G. 1957. The effect of differences in soil moisture status on plant growth: a review and evaluation. Soil Sci. 84: 205-214.

Stevens, O. A. 1963. Handbook of North Dakota Plants (with revision appendix). North Dakota Institute for Regional Studies, Fargo, North Dakota. 324 p.

Swan, J. M. A., R. L. Dix, and C. F. Wehrhahn. 1969. An ordination technique based on the best possible stand-defined axes and its application to vegetation analysis. Ecology 50: 206-212.

Swan, J. M. A. 1970. An examination of some ordination problems by use of simulated vegetational data. Ecology 51: 89-102.

______. 1972. Personal letter.

Thomas, W. A. 1969. Accumulation and cycling of calcium by dogwood trees. Ecol. Monogr. 39: 101-120.

Thornthwaite, C. W. 1948. An approach toward a rational classification of climate. Geogr. Rev. 38: 55-94.

Tukey, H. B., S. H. Wittwer, and M. J. Bukovac. 1962. The uptake and loss of materials by leaves and other above-ground parts with special reference to plant nutrition. Agrochimica 7: 1-28.

Tukey, H. B. Jr. and R. A. Mecklenburg. 1964. Leaching of metabolites from foliage and subsequent reabsorption and redistribution of the leachate in plants. Amer. J. Botany 51: 737-742.

Tukey, H. B. Jr. 1966. Leaching of metabolites from above-ground parts and its implications. Bull. Torrey Bot. Club 93: 385-401.

U. S. Department of Agriculture. 1938. Soils and Men. U. S. Department of Agriculture Yearbook. U. S. Government Printing Office, Washington, D. C. 1232 p.

______. 1951. Soil Survey Manual. U. S. Department of Agriculture Handbook No. 18. U. S. Government Printing Office, Washington, D.C. 503 p.

______. 1960. Soil Classification: A Comprehensive System (7th Approximation). U. S. Government Printing Office, Washington, D.C. 265 p.

______. 1967. Supplement to Soil Classification System (7th Approximation). U. S. Government Printing Office, Washington, D.C. 207 p.

U. S. Department of Commerce, Weather Bureau. 1959. Climate of the states: North Dakota. Climatography of the United States No. 60-32. 15 p.

______. 1967. Climate of Grand Forks, North Dakota. Climatography of the United States No. 20-32. 4 p.

van Groenewoud, H. 1964. Ordination and classification of Swiss and Canadian forests by various biometric and other methods. Ber. Geobot. Inst. ETH. Stiftg. Rubel, Zurich. 36: 28-102.

Veihmeyer, F. J. and A. H. Hendrickson. 1950. Soil moisture in relation to plant growth. Ann. Rev. Plant Physiol. 1: 285-304.

Veihmeyer, F. J. 1956. Soil moisture. p. 64-123. In W. Ruhland (ed.) Pflanzenphysiologie. Band III. Springer-Verlag, Wein.

Wadleigh, C. H. 1946. The integrated soil moisture stress upon a root system in a large container of saline soil. Soil Sci. 61: 225-238.

Wali, M. K., G. F. Gruendling, and D. W. Blinn. 1972. Observations on the nutrient composition of a freshwater lake ecosystem. Arch. Hydrobiol. 69: 452-464.

Wali, M. K. and V. J. Krajina. 1972. Vegetation-environment relationships of some sub-boreal spruce zone ecosystems in British Columbia. Vegetatio 24: 229-371.

Walker, B. H. and C. F. Wehrhahn. 1971. Relationships between derived vegetation gradients and measured environmental variables in Saskatchewan wetlands. Ecology 52: 85-95.

Wanek, J. W. 1967. The gallery forests of the Red River of the North. Ph.D. Thesis. North Dakota State Univ., Fargo, North Dakota.

Waring, R. H. and J. Major. 1964. Some vegetation of the California coastal redwood region in relation to gradients of moisture, nutrients, light, and temperature. Ecol. Monogr. 34: 167-215.

Whitman, W. C. 1954. Vegetation of North Dakota. p. 37-61. In I. T. Dietrich and J. Hove (eds.) Conservation of Natural Resources in North Dakota. North Dakota State Univ., Fargo.

Whittaker, R. H. 1956. Vegetation of the Great Smoky Mountains. Ecol. Monogr. 26: 1-80.

______. 1960. Vegetation of the Siskiyou Mountains, Oregon and California. Ecol. Monogr. 30: 279-338.

______. 1962. Classification of natural communities. Bot. Rev. 28: 1-239.

Whittaker, R. H. and W. A. Niering. 1965. Vegetation of the Santa Catalina Mountains, Arizona: a gradient analysis of the south slope. Ecology 46: 429-452.

Whittaker, R. H. 1967. Gradient analysis of vegetation. Biol. Rev. 42: 207-264.

Witherspoon, J. P. Jr. 1964. Cycling of cesium-134 in white oak trees. Ecol. Monogr. 34: 403-420.

Woodwell, G. M. and R. H. Whittaker. 1967. Primary production and the cation budget of the Brookhaven Forest. p. 151-166. In H. E. Young (ed.) Symposium on Primary Production and Mineral Cycling in Natural Ecosystems. Orono, Maine.