A CONTRIBUTION TO THE PHYTOECOLOGY OF SOUTHERN INDIANA WITH SPECIAL REFERENCE TO CERTAIN ERICACEAE IN A LIMESTONE AREA OF THE BLOOMINGTON QUADRANGLE.

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Since Bloomington is situated in a portion of Indiana which is noted for its limestone, and since the distribution of Ericaceae is thought to be influenced greatly by soil acidity, the writer has been interested especially in studying the distribution of the huckleberry (*Gaylussacia baccata*) and the blueberry (*Vaccinium vacillans*) on cer-

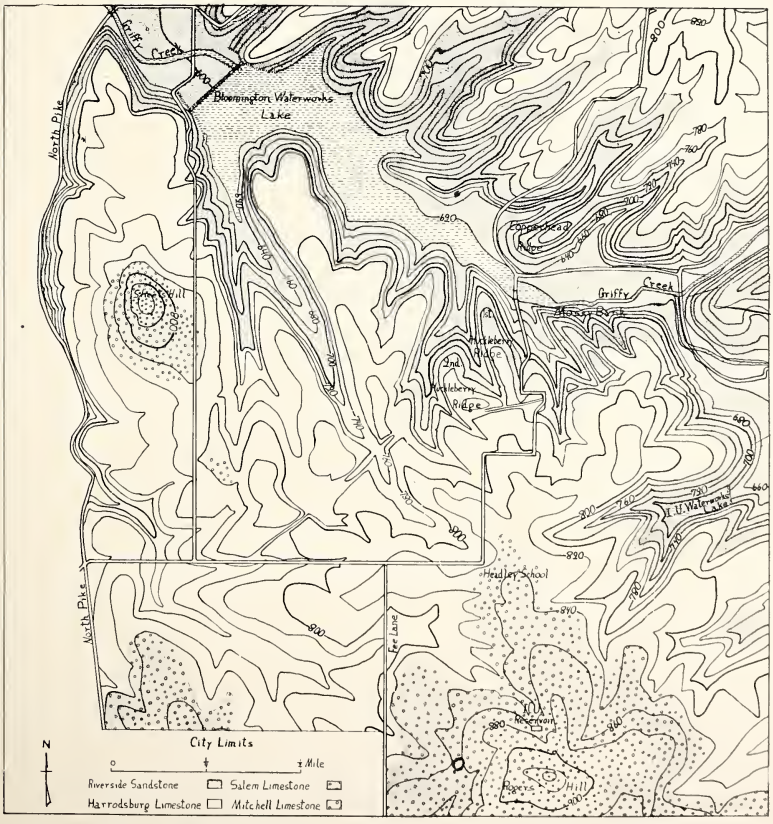

Fig. 1—Map showing the topography and the rock formation.

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tain ridges and slopes northeast of Bloomington, the processes which have produced situations favorable for the growth of Ericaceae in this particular area, and the degree of acidity of the soil in which these plants are most commonly found.

Also, in the same area, a study has been made of plant indicators of soil acidity, two glacial relics near Bloomington, general vegetation and habitats, zones of vegetation at the head of the lake, and hydrarch succession in a solution pond.

Location and Climate of Area. The area chosen for this study consists of four square miles northeast of the city of Bloomington (fig. 1).

The average temperature in the southern part of Indiana for January is 33° F.; for July, 79° F. (14). The mean annual temperature is 52° F. The average rainfall is 42 inches, rather evenly distributed throughout the year (7). The mean relative humidity for Indianapolis (approximately 50 miles northeast of Bloomington) and vicinity is 78 per cent at 7 a.m., 59 per cent at noon, and 64 per cent at 7 p.m. (19).

Topography. This area is a portion of the late Tertiary peneplain and is very much dissected by Griffy Creek and its tributaries. As a result, a series of ridges and ravines extend toward the Griffy Creek Valley. The ravines are small and V-shaped, with steep sides. At the head of each is a steep fall of 10 to 15 feet (10) where the Harrodsburg limestone comes in contact with the Knobstone. After the valleys have reached their local base-levels they are no longer V-shaped, but become flat-bottomed areas with steep ascents on their sides. In the Bloomington Quadrangle, Griffy Creek flows from southeast to northwest. In this particular portion under observation the streams forming the ravines on the north side of the valley flow from northeast to southwest, and those on the south side flow north and northwest.

Geology. "Approximately 30,100 square miles of Indiana have been subjected to glaciation, while only about 6,250 square miles have not been touched by glacial ice. The unglaciated area in the middle-western portion of the southern third of the state is frequently spoken of as the driftless area as opposed to the glaciated area" (11). The largest part of Monroe County lies in the unglaciated portion, and the bedrock formations are well exposed. The Illinoian ice sheet extended farther south in Indiana than either the early or the late phase of the Wisconsin. Figure 2 shows the glacial boundary in the state as determined by C. A. Malott (9), in 1925.

The area included in this investigation lies within the portion of the Bloomington Quadrangle which is occupied by the Knobstone and by the Harrodsburg, Salem, and Mitchell limestones (3). Figure 1 shows the position of the rock outcrops, their thickness, and the manner in which the different formations rest upon each other. The outcrops of the Knobstone and the Harrodsburg limestone occur frequently in the area selected for this study.

Only the upper portion of the Knobstone is exposed in the Bloomington Quadrangle. This part of the formation is known as the Riverside sandstone (8). Approximately 100 feet of the sandstone are exposed

in this vicinity. The Knobstone is visible in the ravines and especially well at the northeast end of the spillway of the Bloomington Water Works Lake. The sandstone consists of fine grains of sand cemented with clay. It is bluish gray in color and weathers to a light or rusty brown.

The Harrodsburg limestone of the Bloomington Quadrangle is from 70 to 90 feet in thickness (15). It is a very coarse limestone and is easily identified by the abundance of geodes and fossil crinoids and brachiopods contained within it. Outcrops of this rock are common on the west-facing slope along North Pike (State Road 37) and are observed frequently at the heads of the ravines. The geode zone of the Harrodsburg lies at the base of the formation and is frequently 15 or more feet in thickness. It extends into the Riverside sandstone for a distance of 10 or more feet (3).

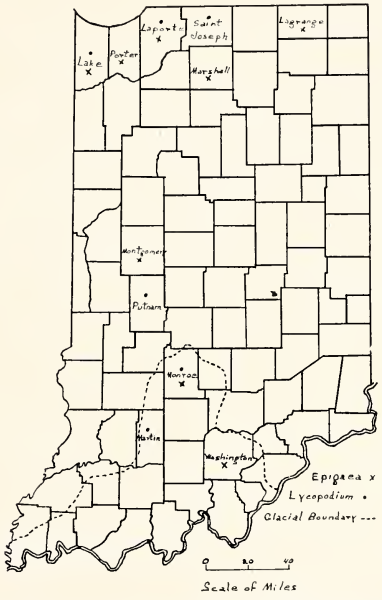

Fig. 2. Outline map of Indiana showing glacial boundary and county distribution of *Lycopodium complanatum* L., var. *flabelliforme* Fernald and *Epigaea repens* L.

Since the influence of the Mitchell and Salem limestones upon the vegetation of this area under study is not different from that of the Harrodsburg, their chief characteristics have been omitted from this discussion.

Beginning with the lowest formations in the Bloomington Quadrangle and passing to the uppermost ones, they occur in the following order: (a) the Knobstone or Borden, (b) the Harrodsburg limestone, (c) the Salem limestone, (d) the Mitchell limestone, (e) the Chester shales, limestones, and sandstones, and (f) the Pottsville or Mansfield sandstone. They occur in the same sequence from the lowest rocks in the valleys on the east to the highest ones on the hills in the southwest

part of the Quadrangle. The lower layers pass under the higher ones to the west or southwest with an average dip of about 34 feet per mile (3).

Method. Excursions were made over the selected area for the purpose of (a) studying all situations in which *Gaylussacia* and *Vaccinium* are growing, (b) observing how these habitats have been produced, (c) collecting soil samples for the determination of pH values, (d) studying the general vegetation and (e) collecting specimens of each species of plants growing within these four square miles.

Approximately 300 soil samples have been collected and the pH value determined by means of the Morgan Soil Testing Set (12). Many of these tests were checked electrometrically and only slight differences (0.1-0.3) in the pH values resulted. Six serial collections were made. Each series consists of samples taken in a direct line from the top of the ridge to the base of the slope. The remaining samples were taken at random, in order to determine the pH value of the soils in which the various species of plants are growing. A soil sample was taken in the following manner: the covering, such as sod, leaves, and debris, was removed, and a few handfuls of soil were dug to a depth of four inches, which is the approximate root level of *Gaylussacia* and *Vaccinium* in this area. After being thoroughly mixed this was placed in a clean, separate container and labeled. The testing was done in the laboratory, using air-dried soil.

Four hundred species of plants were collected from the area under study. Because of the lack of space the enumeration cannot be included with this discussion. The specimens, with a few exceptions, have been identified by the author, mounted, labeled, and preserved in the Indiana University Herbarium. All doubtful identifications have been checked by C. C. Deam, the species of Cuscuta by T. G. Yuncker, and the grasses by Paul Weatherwax.

Distribution of Gaylussacia and Vaccinium. Huckleberries and blueberries grow widely distributed in the eastern part of Monroe County, and occasionally quantities of the fruits are brought to the Bloomington market in season. Second Huckleberry Hill is the point nearest to Bloomington from which these species have been reported. The writer has found these plants growing on slopes in all portions of the area except that which lies west of Second Huckleberry. The geologic and edaphic factors seem to have played the most important part in the distribution of *Gaylussacia baccata* and *Vaccinium vacillans* in this particular region.

The three upper rock formations consist of limestones (figure 1). Cumings (7) states that analyses of the Salem show from 97.9 per cent to 98.4 per cent calcium carbonate, with the balance consisting mostly of clay, and iron oxide, and of the Mitchell, 96.65 per cent to 99.04 per cent calcium and magnesium carbonate, with the balance consisting of clay, and iron oxide. He also states that satisfactory analyses of the Harrodsburg have not been obtained, but that it contains less calcium carbonate than the other two formations.

Most of the slopes along Griffy Creek in the area under consideration are densely wooded, except where man has cleared them for lumber or for fuel. The ridges are pastured or cultivated. Figure 1 shows the wooded slopes and the open ridges, comparable with sandstone and limestone areas respectively.

Since carbon dioxide is produced abundantly by living organisms in the surface layers of woodland soils, and by the decomposition of vegetable matter, the rainwater, as it passes through the atmosphere just above the ground level and through the upper portion of the soil, absorbs the gas, and carbonic acid is formed. This carbonated rainwater has a marked solvent action upon the limestone, dissolving both the calcium and the magnesium carbonate. Leaching is therefore one of the most important factors influencing the distribution of huckleberries and blueberries in a limestone area.

The ravines begin with a steep fall of about 10 or 15 feet at the contact point of the Harrodsburg limestone and the sandstone. An exposure of the limestone commonly occurs at the head of each ravine. The streams have cut their valleys through the higher (limestone) formation into the underlying rock. Because of erosion the limestone has been washed away and the sandstone is the only formation visible on the bottom and sides of the V-shaped ravines. Limestone ledges frequently occur on the sides as well as at the head of the older, U-shaped ravines. But in all cases the sandstone forms the bottom. Geodes are found frequently in these gullies, the presence of which is an indication that the contact between the Knobstone and the Harrodsburg limestone has been reached. Smaller ravines enter the larger ones, and the latter extend into the lake. Frequently young trees ar found lying across the V-shaped ravines, having fallen as the result of erosion. Other evidences of this process are the dead or dying trees and shrubs along the margins of the younger gorges where erosion continuously carries the soil and pieces of rock away from the roots. Occasionally, where sufficient soil has lodged, herbaceous plants grow in these V-shaped ravines.

The bows or bends in the trunks of the trees which grow on the slopes give evidence of slight land-slides. The roots of plants, especially the trees and shrubs, hasten disintegration of the rock. The woods are moist and shady. The sandstone, although not well exposed to the sun's rays, shatters and weathers as a result of freezing and thawing. Often large pieces are broken loose by frost action. As the disintegration and exfoliation continue, conditions are produced eventually which are so unstable that gravity causes landslides. After the slip, the plants readjust themselves to their new surroundings.

Figure 1 shows the dominance of Knobstone slopes along the Griffy Creek Valley, and a comparison of the exposures of this formation makes evident a difference of approximately 100 feet between the Knobstone exposure on the west side of the area, along North Pike, and that on the east. This is due to the dip of the rock formation to the west or the southwest.

The south-facing slope is much more gradual than the one opposing it. The ravines on this side of the lake are longer and more numerous.

These conditions indicate that a greater amount of erosion has occurred on these slopes than on those sloping northward. The difference in weathering of the slopes is due to the effect of changes in the temperature, especially of freezing and thawing, upon the rocks. The slopes facing northward are protected from the rays of the sun and are frozen throughout most of the winter. During the same period, the rocks of the south-facing slopes are repeatedly frozen and thawed, because these slopes are exposed to many more changes of temperature. Therefore a greater amount of soil and exfoliated rock is in condition to slide down the slopes into the ravines and the lake under the influence of gravity, or to be carried down by the water.

Mechanical weathering occurs more rapidly in the sandstone than in the limestone, because the former, due to its power to absorb water, is easily disintegrated by frost action. The exposures of the sandstone are sloping and those of the limestone are vertical. Chemical action occurs much more slowly in siliceous rocks than in calcareous rocks because the carbonate of lime, the essential constituent of ordinary limestone, is highly soluble in carbonated rainwater and, in time, may be completely removed.

The results of erosion are commonly more distinct on the west-facing slopes than on those facing the east, because the former usually have a higher daily temperature than the latter. Thus conditions are produced which are similar to those on south-facing slopes, although they are not so advanced.

Tests show that the soil on the slopes is acid. The writer considers that the following conditions may account, in part at least, for this acidity: (a) the presence of inorganic acids, especially carbonic acid. (b) the presence of various organic acids, and (c) the lack of sufficient basic elements to counteract the acidity.

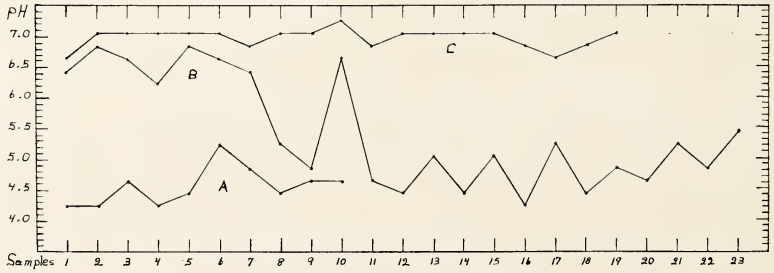

Fig. 3. Variation in soil acidity on three different slopes, A, B, and C, and in different portions of the same slope. In each of the series the first sample was taken at the top of the slope and a direct line was followed to the base. Samples were taken approximately every 20 feet.

The degree of acidity varies on different slopes (table 1) and in different portions of the same slope (fig. 3). The soil of the slopes in the eastern part of the area is more acid than that in the western (table 1), including a distance of only two miles, due to a greater exposure of limestone along North Pike (fig. 1).

Table 1 also shows that, with one exception which is explained in the preceding paragraph, the pH values on the north-facing slopes are higher than on those facing the west. As explained before, less weathering and erosion have occurred on the slopes facing north, and for that reason there still remains sufficient limestone to decrease the soil acidity to that extent.

TABLE 1. The Decrease in acidity of the Soil from the eastern portion to the Western Portion of the Area Studied, and on the North-facing slopes.

Location	pH Range
West-facing slope on east side of area	4.2—4.6
North-facing slope of Mossy Bank	4.6—5.0
West-facing slope of Mossy Bank	4.4—4.6
North-facing slope of First Huckleberry	5.2—6.4
West-facing slope of First Huckleberry	4.2—5.2
All slopes of Second Huckleberry	4.4—6.4
North-facing slope of 1st ridge w of 2nd Huckleberry	5.0—6.6
North-facing slope of ridges between 2nd Huckleberry & North Pike	4.6—7.0
West-facing slope along North Pike	6.6—7.4

The pH values in three series of soil samples are shown in figure 3. Each series was taken on different slopes and shows the variation in acidity in different portions of the same slope. A direct line was followed from the top of the ridge to the base of the slope. Series A was taken on a south-facing slope on the north side of Griffy Creek where blueberries grow abundantly. Series B was collected on a south-facing slope on the north side of Griffy Creek, but no blueberries grow on this slope. This series shows the increase of soil acidity in the lower portion of the slope, which results from leaching and particularly erosion, in the past. In the upper portion, the soil is circumneutral, i. e., between 6.0 and 8.0. Approaching the limestone formation where there are still many fragments of limestone in the soil, the degree of acidity is lessened. The presence of small pieces of limestone is the probable cause of the more extreme irregularities in series A and B. Series C was made on the west-facing slope along North Pike. Limestone outcrops are very frequent and no species of Ericaceae are found on this slope. All the soil in this series is circumneutral, due to the presence of the limestone.

The author has found abundant evidence that the distribution of *G. baccata* and *V. vacillans* in this particular area is closely connected with the acidity of the soil. Having made approximately 100 tests of the soil in which these species are growing throughout the entire area, the pH range has been determined as 4.0 to 5.2, 4.4 being the most frequent value, as is shown in Table 2.

These species grow along the margins of the ridges and on the slopes, usually more abundantly toward the top than the base, and particularly on the points of the ridges, if erosion is not too severe. The direction of slope and the angle, although commonly about 25°, are

not extremely important factors. Although *Gaylussacia* and *Vaccinium* are usually growing more abundantly on south-facing or west-facing slopes in the area under consideration, they may be found occasionally on slopes facing the north. The upper extent to which they grow depends upon the acidity of the soil, which, in turn, is influenced by the amount of limestone in it, and this is dependent, largely, upon the degree to which leaching and erosion have occurred. The lower range is limited by the erosive factor because the roots of the species do not penetrate deeply into the soil.

TABLE 2. Soil Reaction Preferences of *Gaylussacia baccata* and *Vaccinium vacillans*.

Percent of Soil Tests	pH Value
74 plus	4.4
11 plus	4.6
5 plus	4.8
4 plus	5.0
2 plus	4.2
2 plus	5.2
1 plus	4.0

They grow in clumps because they spread chiefly by vegetative means. These plants reach new habitats by dissemination of their fruits and seeds by means of animals, especially birds. Frequently the huckleberries and blueberries are retained by the roots of other shrubs and of trees, or by large pieces of rocks, while the remainder of the slope is bare due to erosion. In a number of instances the depth of the soil in which the Ericaceous plants are growing was measured. In all cases, about four inches below the surface the roots were found to be growing among small pieces of sandstone.

In this specific area *Gaylussacia* and *Vaccinium* show the most luxuriant growth in open or exposed situations. The sandstone soil retains very little moisture because of the clay cement and the fineness of the sand grains. Therefore these species occur in xerarch succession. One of the south-facing slopes shows the following stages from a bare area to the climax forest. This bare area has been produced by water erosion. Beginning at the base of the slope, a few feet above the water's edge, the first plants seen are the fruticose lichens, usually some species of *Cladonia*, and mosses such as *Dicranum scoparium* (L.) Hedw., *Leucobryum glaucum* (L.) Schimp., and *Polytrichum commune* L. Continuing up the slope, grass grows with the pioneers. Still farther upward *Vaccinium vacillans* accompanies the grass, mosses, and lichens. The blueberries are a part of the shrub stage which also includes *Viburnum acerifolium*, but this species occurs a short distance beyond the *Vaccinium*. *Quercus alba*, *Q. velutina*, and *Carya cordiformis*, xeric trees, follow the shrub stage, and grow on the upper slope and the ridge with the climax trees, *Acer saccharum* and *Fagus grandifolia*.

Reasons for the non-occurrence of *Gaylussacia* and *Vaccinium* west of Second Huckleberry follow. The slopes are densely wooded. In these moist and shaded situations the sandstone weathers by exfoliation and forms an unstable substratum. The soil is loose and contains a great amount of humus. The vegetation consists of the climax trees, with their associates, a few large shrubs, and the common woodland herbaceous vegetation. Because of the abundance of root systems, no great amount of soil is carried away by erosion. No exposures of the Knobstone occur except in the V-shaped ravines, where erosion prevents the growth of these shrubs. The limestone has weathered to a lesser extent, and outcrops of this formation occur frequently. As is shown in Tables 1 and 2, the degree of soil acidity is not sufficiently great. Since erosion has not advanced as rapidly on these particular slopes as on others, fragments of limestone resulting from weathering are still sufficiently plentiful in the soil to decrease the soil acidity to the extent that *Gaylussacia* and *Vaccinium* do not grow in this portion of the area. On the upper west-facing slopes there occurs rarely a small, open, dry area on which mosses and fruticose lichens are growing. They are the same species which accompany the huckleberries and blueberries in other habitats. Thus it seems reasonable to predict that sometime in the future when the conditions preferred by *Gaylussacia* and *Vaccinium* exist on these particular slopes, these plants will take their place in the shrub stage of this xeric succession.

Plant Indicators. Throughout the area the author found that certain plants were always growing in acid soil. A list of these species was made and numerous soil samples were tested. Table 3 includes the names and the range of pH values. The asterisk refers to those species which commonly grow in the same society. The others may or may not be found with these.

TABLE 3. Plant Indicators of Acid Soil in This Specific Area.

Species	pH Range
**Gaylussacia baccata*	4.0—4.6
**Dicranum scoparium*	4.2—4.8
Danthonia spicata	4.2—5.0
Monotropa uniflora	4.4—5.0
**Mitchella repens*	3.8—5.2
Pedicularis canadensis	4.4—5.2
**Carex picta*	4.4—5.4
**Leucobryum glaucum*	4.2—5.4
**Polytrichum commune*	4.2—5.4
**Vaccinium vacillans*	4.2—5.4
**Viburnum acerifolium*	4.2—5.6

Glacial Relics. Since the range of *Lycopodium complanatum* L., var. *flabelliforme* Fernald and *Epigaea repens* L. is southern and southeastern Canada and northern and northeastern United States, how did

each of these species reach southern Indiana? Although the question cannot be answered with assurance the following explanation seems probable.

The Illinoian ice sheet reached the Ozark Hills in southern Illinois. A short distance east of the Indiana-Illinois line the glacial drift bends to the northeast and continues this direction to central Indiana (figure 2), where it turns south to the Ohio River, and continues east into Ohio.

While the tundra extended along the front of the ice during the period of glaciation the soil was probably frozen to a great depth, but thawed in summer sufficient for the growth of plants. When the ice retreated in Indiana and Ohio it was separated from the forests by this treeless tundra.

In order to continue with the theory it is necessary to understand the habit and conditions of growth of the species under consideration. *Epigaea repens* spreads over the ground in large patches, by means of branches 6 to 15 inches long which send out roots, a leaf, and flower-bearing stalks every two or three inches. The white, fleshy, juicy fruit contains usually 300 to 500 seeds according to Bailey (2). Since ants, snails, and birds seek the pulp of the fruit it is possible for these animals to disseminate some of the seeds and thus aid in the development of new patches of trailing arbutus in suitable habitats. *Epigaea repens* thrives in acid, sandy, well aerated, moist soils in shady situations (2). Its roots imbedded very shallowly in the soil possess a mycorrhizal fungus (6) which is assumed to be beneficial to the host because it seems to supply the plant with sufficient nitrogen to enable it to live in its chosen habitat.

Figure 3 shows the distribution of *E. repens* in Indiana according to C. C. Deam. The writer has collected it in Monroe County, on Arbutus Hill, four miles east of Bloomington and has seen a specimen which was collected in Washington County. This plant grows also in various other known localities in Monroe and Brown counties. Upon examination of the glacial boundary in Indiana it is noted that Montgomery County has been entirely glaciated, and that small portions of Monroe and Washington counties lie within the limits of the ice sheet. According to the theory of the writer *E. repens* was one of the species growing in the tundra zone along the ice front, and, as the glacier retreated, the plants in the most suitable habitats survived. Thus it is possible for this species under consideration, now growing in Montgomery, Monroe, and Washington counties, to have descended from the trailing arbutus of the tundra.

Perhaps *Epigaea* grew more commonly in southern Indiana following the retreat of the ice than at the present time, and possibly the forest fires started by the Indians have played an important rôle in almost eliminating this beautiful trailing plant from the flora of this part of the state. Or perhaps trailing arbutus always has been of rare occurrence in this portion of North America. In either case, whether common or rare, what has prevented its extinction? The most plausible answer seems to be that this species is found in a habitat which is

much more favorable for its growth than for the majority of the neighboring species. It is probable that soil acidity is the factor to which *E. repens* is so well adapted, and, due to this adaptation, this trailing arbutus has been able to survive in competition with the other plants. The pH values of the soil samples collected on Arbutus Hill are 4.0, 4.2, and 4.4.

Man is fond of the flowers and their fragrance and injures the roots and trailing stems each time a bouquet is gathered. Others collect for transplanting, which is nearly always unsuccessful. These facts account for its low rate of spreading, which occurs chiefly by vegetative means, and, if proper precautions for the preservation of the species are not taken, will bring about the extinction of trailing arbutus in this locality. Otherwise *E. repens* should thrive as long as the necessary soil conditions are present.

The other glacial relic, which the author wishes to consider in this discussion, is *Lycopodium complanatum* L., var. *flabelliforme* Fernald. The sporophyte consists of a long, nearly superficial rhizome which produces roots at intervals from the lower side and erect branches from the upper portion. The spores are produced in cone-like structures which develop at the ends of the several-forked branches and are ripe in August or September. The prothallia of this species are subterranean. They have not been collected in this locality. Stokey and Starr (18), collecting in western Massachusetts, found the prothallia at depths varying from 0.5 to 4.0 centimeters. They also report that in two cases prothallia and sporelings were found within 3 meters of old plants; usually they were 15 to 50 meters apart; occasionally 100 to 200 meters away. Spessard (17) records finding only a few sporelings growing among the plants. A fairly compact, well drained, sandy soil with considerable humus and an adequate supply of moisture, in a shaded area with little or no herbaceous growth, plus the fungus which is assumed to be necessary for the endophytic relationship with the prothallia are the conditions generally found where gametophytes and sporelings of *Lycopodium* have developed.

Blatchley (4) reports *Lycopodium complanatum* L. (probably the variety) as rare on Huckleberry Hill in 1887. Andrews (1) states that he saw it "about 30 years ago on the western slopes of several deep ravines about two miles northeast of Bloomington, Indiana." The author has been informed by the teachers in the Botany Department of Indiana University that the presence of the sporophytes of the ground pine on First and Second Huckleberry Hills is intermittent. One of the professors found them in 1915 and not again until 1922. Since the latter date it has not been reported from that particular region.

In May and October, 1927, the writer visited a community of this club moss on a slope about four miles north of Bloomington. This patch covers an area approximately one rod square, and is located about one-half the way down a high, rather steep, north-facing slope, at the base of which runs a stream. The common trees of this region, such as *Acer saccharum, A. rubrum, Fagus grandifolia, Quercus alba, Q. Prinus, Morus rubra, Prunus serotina, Liriodendron Tulipifera, Nyssa*

sylvatica, Carpinus caroliniana, Ostrya virginiana, Cornus florida, Sassafras variifolium, and *Fraxinus americana,* shade the slope, cover the ground with leaves in the fall, and greatly increase the supply of humus each year. The herbaceous vegetation within the immediate vicinity of *Lycopodium* is scanty and consists of the following species: *Polystichum acrostichoides, Adiantum pedatum, Polytrichum commune,* and *Leucobryum glaucum.* The *Lycopodium* is growing in a soil which is subacid with a pH value of 5.4.

Figure 2 shows the distribution of this species in Indiana by counties. In the southern part of the state it has been reported from Putnam and Monroe counties. The larger portion of the latter lies in the zone which was tundra along the ice front, and probably the ancestors of the *Lycopodium* now growing in Monroe County were growing in the tundra. The entire portion of Putnam County lies in the glaciated area of Indiana, and *Lycopodium* doubtlessly established itself there as the ice retreated. The same points discussed in connection with *Epigaea repens* may be applicable in considering this club moss, namely, forest fires started by the Indians, frequency or rarity of occurrence, and its survival in limited areas under favorable conditions in competition with other plants. The small patch on the hillside mentioned is on private and carefully protected property and is thriving due to its suitable habitat.

According to Stokey and Starr (18) and Spessard (17) the prothallia and sporelings are restricted to places of little or no herbaceous growth. Very few non-woody plants were found near the patch on the above-mentioned slope, but, in this case, another limiting factor enters. Each year there is a considerable deposit of dead leaves, which tends to prevent the majority of the spores from reaching favorable depths in the soil. This may account for the lack of development of new colonies on this slope. Thus the species is spreading slowly by means of its rhizomes.

What has become of the ground pine which has been reported on First and Second Huckleberry Hills? The following explanations may account for the fact that it is not visible at the present time. Hunters, hikers, and picnickers frequently visit these woods. Through their carelessness fires spread over the slopes at various times. If this happens in the fall, the portion of the club moss which is above the ground is sufficiently dry to burn. If the plants are in fruit or beyond this stage the spores are destroyed because they contain oil, which causes them to be highly inflammable. If the fire burns the humus there is a possibility of the destruction of the fungi which are assumed to maintain the necessary symbiotic relationships with the prothallia and, also, of the subterranean gametophytes if they are developing sufficiently near the surface of the soil. If some of the spores and prothallia are not injured or destroyed, they are unable to develop because of the lack of sufficient moisture, due to the decreased amount of humus in the sandstone soil.

An examination of the weather records for a period of years does not show sufficient variation or decrease in precipitation to account, directly, for the death of prothallia or sporelings.

Since *Lycopodium* has become popular for Christmas decorations, man has collected the beautiful fan-like branches for commercial purposes. Upon request, this practice has ceased in this locality, but the period of time has not been long enough for the reappearance of the species.

Even if the conditions are favorable for the germination of the spores, the symbiotic relationships between prothallia and fungi have developed, fertilization has occurred, and the sporelings have started to break through the surface of the ground, the young plants may not survive if they are in an area which is too dry or receives too much sunlight. Such conditions are possible on the Huckleberry Hills due to the removal of trees for lumber or for fuel.

Still another important factor may influence the intermittent presence of *Lycopodium* sporophytes in the areas under observation. The germination of the spores and the growth of the prothallia and sporelings are very slow. No report was found concerning the time necessary for the production of the sporelings of *Lycopodium complanatum*, var. *flabelliforme*, but Bruchmann (5) found that 3 to 5 years are necessary for the germination of the spores of *L. Selago*, and an additional 6 to 8 year period for the maturation of the prothallia, i. e., a total of 9 to 13 years passes from the time the spores are deposited until the gametes are produced. Bruchmann (5) also found that 6 to7 years are necessary for the germination of the spores of *L. clavatum* and *L. annotinum*, and 12 to 15 additional years for the prothallia to reach sexual maturity. Assuming that comparable periods are necessary for *L. complanatum*, var. *flabelliforme*, it is possible that spores deposited several years ago by this species on the Huckleberry Ridges may be in the process of germination or the prothallia may be in some stage of development and at some future date *L. complanatum*, var. *flabelliforme* may be reported again in this particular habitat.

General Vegetation and Habitats. The dominant species are *Fagus grandifolia* and *Acer saccharum*. The most common secondary trees are *Quercus alba, Q. velutina, Q. rubra, Q. Prinus, Carya ovata, C. glabra, C. cordiformis, Fraxinus americana, F. quadrangulata, Ulmus americana, U. fulva, Morus rubra, Acer rubrum, Aesculus glabra, Liriodendron Tulipifera, Platanus occidentalis, Juglans nigra, J. cinerea, Celtis occidentalis, Prunus serotina, Tilia americana, Nyssa sylvatica*, and *Gleditsia triacanthos*.

The small trees occurring most abundantly are *Juniperus virginiana, Populus grandidentata, Carpinus caroliniana, Ostrya virginiana, Asimina triloba, Sassafras variifolium, Pyrus coronaria, Crataegus* sp., *C. punctata, Cercis canadensis*, and *Cornus florida*.

Of the subdominant species, the shrubs are the most conspicuous. Those which occur most frequently include *Salix nigra, Benzoin aestivale, Hydrangea arborescens, Ribes Cynosbati, Hamamelis virginiana, Rubus occidentalis, R. allegheniensis, Rosa setigera, Rhus copallina, R. glabra, Evonymus atropurpureus, Gaylussacia baccata, Vaccinium vacillans, Viburnum acerifolium, V. prunifolium*, and *Sambucus canadensis*.

Various species of ferns, such mosses as *Dicranum scoparium, Leucobryum glaucum,* and *Polytrichum commune,* lichens, and a liverwort, *Conocephalum conicum,* are the most frequent members of the cryptogamic societies.

As previously mentioned, the enumeration of the species cannot be included with this discussion. The majority of the herbs is omitted because their number is large.

On the sides of the steep, moist, shaded, V-shaped ravines, the most common species include *Phegopteris hexagonoptera, Adiantum pedatum, Asplenium platyneuron, A. angustifolium, A. acrostichoides, A. Filix-femina, Polystichum acrostichoides, Aspidium noveboracense, A. spinulosum, Cystopteris fragilis, Arisaema triphyllum, Uvularia grandiflora, Polygonatum biflorum, Laportea canadensis, Pilea pumila, Asarum canadense, Aristolochia Serpentaria, Polygonum scandens, Hepatica acutiloba, Stylophorum diphyllum, Iodanthus pinnatifidus, Cardamine pennsylvanica, Impatiens pallida, I. biflora, Sanicula canadensis, Thaspium aureum, Collinsonia canadensis, Galium circaezans, G. concinnum, Houstonia purpurea, Campanula americana, Eupatorium urticaefolium, Solidago caesia, S. latifolia,* and *Aster cordifolius.*

The old ravines are open, broad, and flat-bottomed. In the mouths or along the streams the species most frequently found, excluding the common trees and shrubs, are *Typha latifolia, Potamogeton* sp., *Salix nigra, Pilea pumila, Rumex obtusifolius, Polygonum acre, P. sagittatum, P. scandens, Phytolacca decandra, Penthorum sedoides, Impatiens pallida, I. biflora, Hypericum punctatum, Viola striata, Ludvigia palustris, Lysimachia Nummularia, Cuscuta Gronovii, Lappula virginiana, Nepeta hederacea, Lycopus uniflorus, Mentha spicata, Physalis pubescens, Echinocystis lobata, Lobelia siphilitica, Vernonia altissima, Eupatorium urticaefolium, Actinomeris alternifolia,* and *Erechtites hieracifolia,* in addition to the ruderals.

Camptosorus rhizophyllus, Trillium nivale, Aquilegia canadensis, and *Dirca palustris* were found only on the limestone ledges which occur frequently on the west-facing slope along North Pike.

Zones of Vegetation at the Head of the Lake. Before the building of the dam of the Bloomington Water Works, the bottom of this part of the Griffy Creek Valley was under cultivation. The dam was under construction from April, 1924 to March, 1925. As a result, a portion of the valley east of the dam, an area about one mile in length, is entirely flooded, and, as the water backs against the embankment at the east end of the lake, some of it passes under the bridge and up the creek for about one-eighth of a mile. On the east side of the bridge, the zones of vegetation from the north edge of the backwater, up the moderate, south-facing slope of Copperhead Ridge are very distinct. The most common species in each zone follow.

First Zone—Floating aquatics at margin of lake: *Potamogeton* sp. and algae.

Second Zone—Grasses, sedges, rushes, etc. These species grow in the mud just back of the water's edge: *Echinochloa crusgalli, Panicum dichotomiflorum, P. huachucae,* var. *silvicola, Muhlenbergia mexicana,*

Eleocharis obtusa, *Juncus acuminatus*, *J. tenuis*, var. *anthelatus*, *Polygonum pennsylvanicum*, and *Bidens frondosa*.

Third Zone—Cat-tail, sedges, etc.: *Typha latifolia*, *Cyperus strigosus*, var. *compositus*, *Scirpus pedicellatus*, *Salix nigra*, and *Solidago graminifolia*.

Fourth Zone—Ruderals, etc.: *Andropogon virginicus*, *Setaria glauca*, *Smilax hispida*, *Rumex crispus*, *R. Acetosella*, *R. obtusifolius*, *Polygonum pennsylvanicum*, *Lepidium virginicum*, *Potentilla monspeliensis*, *P. canadensis*, *Geum canadense*, *Trifolium pratense*, *T. repens*, *T. hybridum*, *Melilotus alba*, *Desmodium Dillenii*, *Strophostyles helvola*, *Oxalis corniculata*, *Acalypha virginica*, *Euphorbia Preslii*, *Hypericum mutilum*, *Oenothera biennis*, *Gaura biennis*, *Daucus Carota*, *Steironema lanceolatum*, *Apocynum cannabinum*, *Asclepias incarnata*, *A. syriaca*, *Ipomoea hederacea*, *Cuscuta arvensis*, *Verbena urticaefolia*, *Prunella vulgaris*, *Hedeoma pulegioides*, *Solanum nigrum*, *Plantago Rugelii*, *P. lanceolata*, *P. aristata*, *Lobelia siphilitica*, *Vernonia altissima*, *Eupatorium perfoliatum*, *E. urticaefolium*, *Solidago nemoralis*, *S. altissima*, *Aster cordifolius*, *A. dumosus*, *A. ericoides*, var. *villosus*, *Erigeron canadensis*, *Gnaphalium polycephalum*, *Ambrosia trifida*, *A. artemisiifolia*, *Xanthium canadense*, *Helianthus tuberosus*, *Achillea Millefolium*, *Chrysanthemum Leucanthemum*, *Erechtites hieracifolia*, *Lactuca floridana*, and *Hieracium scabrum*.

Fifth Zone—Shrubs, small trees, and lianas: *Rubus allegheniensis*, *Rhus glabra*, *R. copallina*, *Salix nigra*, *Ulmus americana*, *Liriodendron Tulipifera*, *Sassafras variifolium*, *Liquidambar Styraciflua*, *Platanus occidentalis*, *Cornus florida*, *Fraxinus americana*, *F. pennsylvanica*, *Smilax hispida*, *Rhus Toxicodendron*, and *Vitis aestivalis*.

Sixth Zone—Secondary and climax trees. These species have been given in the discussion of the general vegetation and need not be repeated. The ferns growing on the slope are *Asplenium platyneuron*, *Polystichum acrostichoides*, and *Botrychium obliquum*.

The plants growing along the upper portion of Griffy Creek, along roadsides, and in the woods on the surrounding ridges and slopes have been the source of the propagative structures which have produced these vegetative zones.

The chief agents of dissemination of the plants in the first three zones have been water, birds, and wind. The latter has also played an important part in disseminating the species of Compositae. Approximately one-third of the plants in the fourth zone belong to that family. The number of plants belonging to each species of this family is much larger than that of any other species on the slope. Many squirrels and birds live in and among the trees and shrubs. These animals and the wind are responsible for scattering the seeds and fruits of the woody plants upon Copperhead Ridge.

Hydrarch Succession in a Solution Pond. Rogers Hill is 940 feet above sea level, the highest point in the area selected for this study. Figure 1 shows the exact location and the rock formations of this hill. The presence of Mitchell limestone capping the hill indicates at once the origin of this sink hole or the Hill Pond, as it is commonly known.

Since Scott (13) has discussed in detail the geology of this sink hole, the writer will only briefly review the chief steps in its formation.

Mitchell limestone is rather impervious and contains numerous vertical joint-planes. Originally this sink hole was probably a funnel-shaped cavity in the rock and collected the water which drained from the crest of the hill about 16 feet above it. The pond is located south of the east end of the Indiana University Reservoir and a few rods southwest of the summit of the hill. Mitchell limestone favors the development of sink holes, because the carbonated meteoric water dissolves the almost pure limestone as it percolates through the joint-planes instead of being absorbed by the rather impervious rock. This passage of water continues as long as there is an outlet into the other stone beneath it. But at some stage this outlet may become obstructed and then the sink hole is a pond. Such is true in this particular case. The accumulation of silt and plant débris in the bottom of the obstructed funnel leads to the destruction of the pond.

The history of the Hill Pond since 1887 is known. Scott (13) states that it was eight or nine feet deep at that time; that in 1910 it was 46 inches in depth, 70 feet in length, and 57 feet in width; and that a narrow zone of grass, *Bidens,* and *Carex* surrounded the pond. In his paper he lists the algae which grew there in 1910. *Closterium Dianae* Ehrb., *Cosmarium Botrytis* Menegh., *Spirogyra majuscula* Kuetzing, *Oedogonium undulatum* (Bréb.) A. Braun, and *Chaetophora pisiformis* (Roth) Ag. occurred commonly, and *Cosmarium tetraophthalmum* (Kg.) Bréb. and *Docidium crenulatum* (Ehrb.) Rab. were found rarely. *Zygnema stellum* Ag. was collected on two occasions. He continues to say that "*Typha latifolia* L. is the most conspicuous plant in the pond. It covered the shallower two-thirds of the pond in 1908 and has since increased to about three-fourths of the total area. *Alisma Plantago-aquatica* L. occurs sparsely at the margin of the pond. *Veronica Anagallis-aquatica* L. covers the bottom between the *Typha* stalks on the north and east sides of the pond."

The author has been informed by a student of the plankton in 1914 that at that time there was a margin of *Typha latifolia* and the remainder was covered with floating aquatics, such as *Lemna, Wolffia,* and *Ricciocarpus.*

On October 25, 1927, and February 3, 1928, the writer visited the pond. On the former date the pond was dry, and the species of plants were noted. On the latter date measurements were taken, every 10 feet, when the pond was covered with ice to a depth of four to five inches. The maximum width is now 51 feet, length, 66 feet, and depth, 27 inches at the upper surface of the ice. Comparing with Scott's data of 1908 to 1910, there is a difference of four feet in the length, six feet in width, and 19 inches in depth. This variation in dimensions is the result of the accumulation of silt and plant débris over a period of 20 years, and of drainage. A ditch has been dug in the southwest part so that the water is lowered to its present level, the overflow passing down the slope.

Zygnema stellum Ag. is abundant at the north end of the pond and extends into the center. The water in which it grows varies in depth from 9 to 25 inches. *Typha latifolia* is scattered through the central portion of the pond and extends to within three feet of the edge of the water. *Echinochloa crusgalli* accompanies *Typha latifolia* in the shallower portions and forms a zone between the area occupied by *Typha* and the margin in some parts of the pond. The depth of the water in which the cat-tail stage is dominant varies from 12 inches on the east side of the pond to 27 inches in the northwest part. As noted above this is the deepest place in the pond and occurs about 11 feet from the water's edge. On the east side, extending in a southwestward direction, is a zone of *Cephalanthus occidentalis* six feet wide and nine feet long. The water is nine inches deep at the inner extremity of the zone.

No margin occurs at the north end, but one extends around the remainder of the pond and reaches a width of approximately 8 to 14 feet on the sides and at the south end. Its absence in the northern portion is due to the attempts of the landowner to excavate the pond. At one time the farmer wished to drain the pond to keep stock and students away from it. At another time he desired to rid the pond of all vegetation in order to supply his cattle with water. In either case, the plant succession is influenced considerably. The following are the most common plants in the marginal zone: *Polygonum pennsylvanicum, Acalypha virginica, Ambrosia artemisiifolia,* and *Bidens frondosa.*

The chief agents bringing reproductive bodies and vegetative portions of plants to the solution pond are wind and animals, especially water birds. They fly from one body of water to another, carrying plant parts in the mud which adheres to their feet.

The stages in the hydrarch succession in the Hill Pond from 1887 to 1927 have occurred in the following order, although two or more may have existed at the same time: (a) alga and duckweed, (b) cat-tail, (c) sedge and grass, and (d) shrub. The normal succession has been and is still being disturbed by excavation and drainage.

Summary. This is the first of a series of studies the author has planned concerning the phytoecology of southern Indiana and includes a study of (a) distribution of *Gaylussacia baccata* and *Vaccinium vacillans* in a limestone area of the Bloomington Quadrangle, Monroe County, Indiana, (b) plants which are indicators of soil acidity in this specific locality, (c) *Epigaea repens* and *Lycopodium complanatum,* var. *flabelliforme* as glacial relics, (d) general vegetation and habitats, (e) vegetation zones at the head of the lake, and (f) hydrarch succession in a solution pond. The part of Monroe County considered in this study lies in the driftless part of Indiana, and the surface rocks of the area belong to the subcarboniferous or Mississippian Period.

Before *Gaylussacia* and *Vaccinium* can grow naturally in this limestone area it seems to be necessary for leaching and erosion to occur. These processes remove sufficiently the lime carbonate. In the absence of its neutralizing influence the inorganic and organic acids cause the soil to be sufficiently acid for the growth of these plants. In this locality, the huckleberries and blueberries commonly grow in sandstone

soil which has a pH value of 4.4. If the factor of erosion is too strong, these shrubs are removed from the slopes because their roots are imbedded shallowly in the soil. *Gaylussacia* and *Vaccinium* occur in a xerarch succession and are preceded commonly by lichens, *Dicranum scoparium, Leucobryum glaucum, Polytrichum commune, Danthonia spicata, Carex picta,* and *Mitchella repens.*

The following species of plants have been found to be indicators of acid soil in this specific area: *Dicranum scoparium, Leucobryum glaucum, Polytrichum commune, Lycopodium complanatum,* var. *flabelliforme, Danthonia spicata, Carex picta, Michella repens, Monotropa uniflora, Epigaea repens, Pedicularis canadensis, Gaylussacia baccata, Vaccinium vacillans,* and *Viburnum acerifolium.*

Epigaea repens and *Lycopodium complanatum,* var. *flabelliforme,* are out of their natural range in southern Indiana. As the glacial ice advanced, these plants grew in the tundra, and as the ice retreated, they remained in suitable habitats. These glacial relics are surviving the competition with other plants but are not spreading noticeably at the present time.

The area under study is a part of the climax forest. The dominant trees are *Acer saccharum* and *Fagus grandifolia.*

The zones of vegetation on the south-facing slope of Copperhead Ridge indicate the most common species and the stages in the secondary succession which may occur at the head of the lake providing the sere is undisturbed.

Additions have been made to the record of plant succession in the solution pond on Rogers Hill, the history of which has been known since 1887.

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LITERATURE CITED.

1. Andrews, F. M. *Lycopodium complanatum.* Proc. Ind. Acad. Sci. *36:* 227-229. 1926.
2. Bailey, L. H. Standard Cyclopedia of Horticulture *11:* 1120. 1914.
3. Beede, J. W. Geology of Bloomington Quadrangle. Ind. Dept. Geol. Nat. Res. *39:* 190-217. 1914.
4. Blatchley, W. S. The Flora of Monroe County, Indiana. 1887: 104. (Manuscript in Botany Library, Indiana University.)
5. Bruchmann, H. Die Keimung der Sporen und die Entwicklung der Prothallien von *Lycopodium clavatum* L., *L. annotinum* L., und *L. Selago* L. Flora *101:* 220-268. 1910.
6. Coville, Frederick V. The Cultivation of the Mayflower. National Geographic Magazine *28:* 518-519. 1915.
7. Cumings, E. R. On the Weathering of the Subcarboniferous Limestones of Southern Indiana. Proc. Ind. Acad. Sci. *15:* 85-100. 1905.
8. Hopkins, T. C. The Carboniferous Sandstones of Western Indiana. Ind. Dept. Geol. Nat. Res. *20:* 317. 1895.

9. Malott, C. A. The Glacial Boundary in Indiana. Proc. Ind. Acad. Sci. *35:* 93-108. 1925.
10. Malott, C. A. Glacial Geology. Ind. Dept. Geol. Nat. Res. *39:* 217-230. 1914.
11. Malott, C. A. The Physiography of Indiana. Handbook of Indiana Geology. Indiana Dept. Conserv. 1922: 79.
12. Morgan, M. F., A New Field Method for pH Determination. Ecology *8:* 387-388. 1927.
13. Scott, Will. The Fauna of a Solution Pond. Proc. Ind. Acad. Sci. *20:* 395-440. 1910.
14. Scott, Will. Naturalist's Guide to the Americas. 1926: 372-373.
15. Siebenthal, C. E. General Geographical and Stratigraphical Features of the Bedford Oölitic Limestone. Ind. Dept. Geol. Nat. Res. *21:* 296. 1896.
16. Spessard, E. A. Prothallia of *Lycopodium* in America. Bot. Gaz. *63:* 66-76. 1917.
17. Spessard, E. A. Prothallia of *Lycopodium* in America. Bot. Gaz. *74:* 392-413. 1922.
18. Stokey, Alma G. and Starr, Anna M. *Lycopodium* Prothallia in Western Massachusetts. Bot. Gaz. *77:* 80-89. 1924.
19. United States Department of Agriculture Weather Bureau. Indianapolis. 1925.
20. United States Geological Survey. Washington, D. C.