To Mr. Horace Kephart
with the best regards of
Stanley A. Cain

Butler University Botanical Studies
Volume I   *Paper No. 13*

December, 1930

An Ecological Study of the Heath Balds of the Great Smoky Mountains

STANLEY A. CAIN

This Paper Concludes Volume I

This paper is contribution No. 23 from the botany laboratories of Butler University. Address all communications regarding them to Butler University Botanical Studies, Butler University, Indianapolis, Indiana, U. S. A.

LIBRARY
GREAT SMOKY MOUNTAINS
NATIONAL PARK

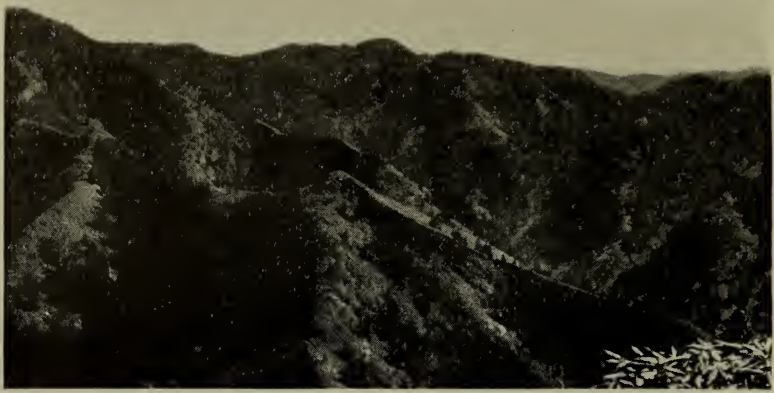


Figure 1. Ridge-type heath balds in the spruce-fir subalpine zone, between Mt. LeConte and the North Carolina-Tennessee state line, Great Smoky mountains. Photograph by courtesy of Jim Thompson Co., Knoxville.

Figure 2. Detail of vegetation at the margin of a heath bald of the type illustrated in Figure 1, at approximately 6,500 feet elevation on Mt. LeConte.

AN ECOLOGICAL STUDY OF THE HEATH BALDS OF THE GREAT SMOKY MOUNTAINS

By Stanley A. Cain

The inhabitants of the Great Smoky mountains usually refer to the heath communities under consideration as "slicks" or "balds." The former name is derived from the smooth appearance they present on the ridges and mountain tops when viewed from a distance and which is entirely misleading, for they are extremely rough and tangled. The name "bald" refers to the absence of trees, these areas being exclusively occupied by shrubs. The term "heath bald" is used in this paper to include all such treeless areas dominated by members of the order Ericales. The use of the term "heath" is not entirely satisfactory, since there is considerable confusion in the literature in respect to the exact meaning of such terms as "heath," "low moor," "high moor," etc., yet no substitute for the term has been found.

One derives from Tansley, in "Types of British Vegetation," that heathland involves poor, dry, sandy soils, usually with a thin layer of dry peat or "trochentorf." The climate can best be described as oceanic where heathland is characteristic, and where the rainfall is greater, up to forty and sixty inches, relatively pure acid humus may develop to a foot in depth. This type of community is considered by Warming (23) under the heading "Dwarf Shrub Heath," where he says that in the Alps, associated with the forest and above the timber line, heaths are formed by various plants, and that in Azalea-heath the layer of raw humus may attain a thickness of half a meter. In distinction to Tansley, Warming considers the production of raw humus as the most characteristic peculiarity of heath, while they agree in respect to the climatic conditions. Warming states that the "dwarf shrub heath occurs only in arctic and alpine sites, also in the oceanic west coasts of the cold-temperate zone that are characterized by cool summers."

In the Great Smoky mountains, areas of heath are to be found with a development of dry peat, particularly at lower altitudes, but the majority of the heath balds have a remarkable development of moist, fibrous brown peat, frequently to a depth of one and two feet. The surface of the peat under the ericaceous shrubs is frequently covered with a dense mat of Sphagnum and other peat-forming mosses. Other species of moss and lichens, as Cladonia and Usnea, may be festooned over the branches, particularly when the balds are at an elevation of 6,000 feet or more.

The presence of peat-forming mosses suggests the possible application of the term "moor" or "high-moor" to these areas. Warming (23), page 200, says: "The moor known as high-moor, Sphagnum-moor or heather-moor, is mainly formed by bog-moss (Sphagnum) and arises on moist soil, which is only slightly permeable to water, though very damp air hangs over it. Humid air and dew are essential to sphagnum-moor, which acquires the whole of its moisture from atmospheric precipitations. It often arises on top of old low-moor; it may also take origin on wet sand, and even on rocks if these be frequently wet, as on the west coast of Norway and Sweden." Thus it would seem that the distinction between moor and heath rests on the presence or absence of Sphagnum; yet heather-moor and dwarf shrub heath, from descriptions, are frequently indistinguishable. However, the following differences between the peat-forming areas of the Great Smoky mountains and true high-moor occur to the writer as distinguishing the two: (1) the high-moor has a convex surface like a watch glass (the sort of thing known as "raised bog" in this country); (2) the high-moor is characterized by the presence of "carnivorous" plants. Altogether, the term "heath bald" seems preferable to "moor" in this connection.

The term "pine-heath," or kiefern-heide, is not subject to the same confusion, since the pines are associated with the heath shrubs under conditions too dry for Sphagnum and the formation of moist brown peat. Harshberger (19 and 20), in describing the New Jersey Pine Barrens, says that "pine-heath is found where the climate is continental." In comparison with the climate of the heath districts, the pine-heath regions are marked by increase in range of annual and diurnal temperatures, rainfall is less, skies are more frequently cloudless and the air is drier and dustier. In the Great Smoky mountains the pine-heath is quite constant in aspect, but the heath balds show a number of facies, the principal variations of which are tied up with changes concomitant with increased altitude.

Distribution of Heath Balds and Pine-Heath in the Great Smoky Mountains of North Carolina and Tennessee

The principal region of heath balds is in the vicinity of the North Carolina-Tennessee state line, from Laurel Top along the Sawtooth range to Mt. Collins, westward on Mt. LeConte and the intervening territory, and southwestward to the limits of the spruce. In this region, in the very heart of the roughest mountains of the area, are to be found the steep ridges and peaks, barren of trees, yet clothed with the densest imaginable growth of ericaceous shrubs. Mt. Guyot to the northeast and Clingman's Dome to the southwest, the two highest peaks in the Great Smoky mountains, approximately mark off this region of numerous heath balds of the type under consideration. These two mountains are themselves essentially without such areas, a phenomenon probably related to their more bulky and less precipitous form. Below Clingman's Dome the heath balds are less frequent until in the southwestern part of the Great Smoky mountain National Park area, from Thunderhead mountain to the Little Tennessee river, they are entirely absent, being replaced by grassy balds. This lower, more southern region is also without the spruce-fir formation which stops south of Clingman's Dome about at Double Spring Gap. To the north and east the heath bald is to be found in varying frequency and character as far at least as the Craggy mountains, where they have been described by Davis (5). The present work has, in the main, been done in the vicinity of Mt. LeConte, because of greater accessibility, although excursions have been made to all parts of the range.

The heath balds are to be found at the tops of ridges and peaks with all exposures and with varying degrees of slope. It has not been possible to correlate the balds with southern exposure, for example, or merely with the angle of slope, although the latter may sometimes be an important factor. They may occur merely as narrow strips along knife-edge ridges, as on Beartrap lead or the Alum Cave balds, or they may occupy the top and extensive upper slopes of a mountain, as in the case of Brushy mountain north of Mt. LeConte.

The pine-heaths occur generally at lower elevations than the heath balds and in many respects occupy comparable positions. Pine-heath is particularly abundant between 3,000 and 4,000 feet in elevation on south exposures. In such situations the pine-heath frequently extends to the top of the mountain or ridge, as in the case of Piney mountain or Bullhead, where there is an extremely sharp line of transition to chestnut or oak forest. Down the slope on all sides these pine and hardwood forests merge gradually into the so-called "cove" forests of greater luxurience and productiveness.

Description of the Vegetation of Heath Balds: Species Content and Relation to Surrounding Forests

Before pointing out the peculiarities of the heath balds and their relationship to the adjacent forest types, it will be necessary to consider briefly the major aspects of the vegetation of the region as a whole. The vegetation areas of the Great Smoky mountains present some confusion when classifications are attempted, especially on a single basis.

The major distinctions should be apparent and consist of climatically controlled vegetational units capable of reproducing themselves and consequently resulting in various dynamic subdivisions related to many factors, yet tending always towards the climax condition of relative stability. This concept of major divisions of vegetation, as established by Schimper and adequately presented recently in Weaver and Clement's (24) Plant Ecology, provides for only two formations in the region of the Great Smoky mountains, namely:

Subalpine Forest: Picea-Abies Formation.
Deciduous Forest: Quercus-Fagus Formation.

The Picea-Abies formation is easily disposed of, since it has a remarkable floristic homogeneity. In Tennessee and North Carolina, or in New England or Southern Canada, it is essentially the same. It is not so with the deciduous forest, which has been variously handled by ecologists and foresters. Weaver and Clement's subdivisions are as follows:

Deciduous Forest: Quercus-Fagus Formation

1. Maple-beech forest: Acer-Fagus association.
2. Oak-chestnut forest: Quercus-Castanea association.
3. Oak-hickory forest: Quercus-Hicoria association.
    a. Pine subclimax: Pinus associes.

The Committee on Forest Type Classification, Frothingham, *et al.* (8), have given us the following convenient grouping for the forest types of the Southern Appalachians:

Northern Forest (mostly at high altitudes)—1, Spruce-fir type; 2, Hemlock-yellow birch type; 3, Northern hardwood type.

Moist Slope and Cove Forest—4 to 11 (types based on importance of different species).

Dry Slope and Ridge Forest—12, Chestnut oak type; 13, Black oak-scarlet oak type; 14, Pitch pine-mountain pine type.

The following tabulation (Table I) presents the flora of the heath balds with an indication of the forest type with which each species is most frequently associated. The column numbers in the tabulation indicate the following main types selected from the above classifications: (1) Spruce-fir forest, (2) Northern hardwoods forest, (3) Upper cove forest, (4) Chestnut-oak forest, and (5) Pine-heath (pine subclimax).

The preceding table emphasizes a number of points about the flora of the heath balds. In the first place, it is striking that there are so few species. The observations on which these results are based were made during four years, in early spring and from June to middle September. At no time is there any display of herbaceous elements, although numbers of these heath balds were visited during this time. The flora is conspicuously woody, 74 per cent. As shown in the tabulation, 47 per cent of the woody flora is found in one family, Ericaceæ, which includes all the dominants.

Since heath balds occur at all altitudes from 4,000 feet to 6,500 feet, it would be expected that the species content would vary somewhat with altitude. This is the case, and not only are some of the species different in the heath balds at Myrtle Point and Main Top, at about 6,500 feet on Mt. LeConte, but the relative abundance and dominance of certain species, common to them and to balds at lower elevations, are different. The flora of balds occurring at higher elevations is distinctly related to the spruce-fir formation. On the other hand, the balds at lower elevations, like Ball mountain and Bullhead mountain, show definite relation to chestnut-oak and pine-heath associations. Intermediate situations like Chimney Caps, Buffalohead, Scratchbritches, etc., are more nearly related to the cove forests and the northern hardwoods.

TABLE I

Flora of the Heath Balds and Relation of Species to Principal Forest Types[1]

Flora	Forest Types 1	2	3	4	5
Polypodiaceæ					
Pteris aquilina	..	..	..	x	x
Aspidium spinulosum intermedium	x	..	..	..	..
Dicksonia punctilobula	..	..	..	x	..
Osmundaceæ					
Osmunda cinnamomea	..	x	x	..	..
Lycopodiaceæ					
Lycopodium complanatum	..	..	..	..	x
Pinaceæ					
Pinus pungens	..	..	..	..	x
Picea rubra	x	..	..	..	..
Abies fraseri	x	..	..	..	..
Liliaceæ					
Trillium undulatum	x	..	..	..	..
Smilax rotundifolia	..	..	..	x	x
Orchidaceæ					
Habenaria ciliaris	..	..	..	x	x
Fagaceæ					
Castanea dentata	..	..	..	x	..
Magnoliaceæ					
Magnolia fraseri	..	x	x	..	..
Lauraceæ					
Sassafras variifolium	..	..	..	x	x
Saxifragaceæ					
Saxifraga leucanthemifolia	x	..	..	..	..
Ribes prostratum	x	..	..	..	..
Hamamelidaceæ					
Hamamelis virginiana	..	..	..	x	..
Rosaceæ					
Pyrus americana	x	..	..	..	..
P. melanocarpa	..	x	..	..	..
Amelanchier canadensis	..	x	..	..	..
Geum peckii	x	..	..	..	..
Rubus canadensis	x	..	..	..	..
Prunus pennsylvanica	x	..	..	..	..
Leguminosæ					
Robinia pseudo-acacia	..	..	..	x	x
Anacardiaceæ					
Rhus copallina	..	..	..	x	x
Aquifoliaceæ					
Ilex monticola	..	x	..	..	..
Aceraceæ					
Acer rubrum	..	x	..	..	..
Cornaceæ					
Nyssa sylvatica	..	..	..	x	..
Ericaceæ					
Clethra acuminata	..	..	..	x	x
Monotropa uniflora	x	..	x	..	..
Rhododendron maximum	x	..	x	..	..
R. catawbiense	x	..	..	..	..
R. punctatum	x	..	..	..	..
Menziesia pilosa	x	..	..	..	..
Dendrium prostratum	x	..	..	..	..
Kalmia latifolia	x	..	x	..	..
Leucothoe catesbæi	..	..	x	..	..
Andromeda floribunda	..	..	..	x	x
Lyonia ligustrina	..	..	..	x	x
Oxydendrum arboreum	..	..	..	x	x
Epigæa repens	..	..	..	..	x
Gaultheria procumbens	..	..	..	..	x
Gaylussacia ursina	..	..	..	x	..
G. baccata	..	..	..	..	x
Vaccinium arboreum	x	..	..	..	..
V. corymbosum	x	..	..	..	..
V. corymbosum pallidum	x	..	..	..	..
V. erythrocarpum	x	..	..	..	..
Diapensiaceæ					
Galax aphylla	..	..	x	x	x
Gentianaceæ					
Gentiana linearis	x	..	..	..	..
Scrophulariaceæ					
Melampyrum lineare	..	..	..	x	x
Caprifoliaceæ					
Diervilla sessilifolia	x	..	..	..	..
Viburnum cassinoides	x	..	..	..	..
Compositæ					
Solidago glomerata	x	x	..	..	..

Summary—54 species are listed in the flora of the balds; 40 species (74 per cent) are shrubs, or, in some cases, scrubby trees; 21 species (39 per cent) of the total flora belong to the Ericales (with one exception, the Ericaceæ of Gray); 19 species of the woody plants (47.5 per cent) belong to the Ericaceæ.

[1]Nomenclature after Gray as far as possible, otherwise after Small.

The main point to be derived in this connection is that the species in the heath balds are for the most part to be found also in the adjacent forests. In other words, they do not have a very great fidelity to the heath bald communities. On the peaks and ridges these shrub species develop an exclusiveness and luxurience that makes them stand out as islands in the surrounding forests. At the same time, however, the heath balds maintain a similarity in physiognomy despite the changing species content. The relation of the bald species to altitude, which is in reality the relation to the contiguous forest type, is brought out in the following table (II), the columns of which are numbered as follows:

6,500 Feet, Approximate Altitude—1, Mt. LeConte, Maintop bald; 2, Mt. LeConte, West Point bald; 3, Mt. LeConte, Balsamtop bald; 4, Mt. LeConte, South Balsamtop bald; 5, Mt. LeConte, East Point bald; 6, Mt. LeConte, Myrtle Point bald.

5,000 Feet Approximate Altitude—1, Brushy mountain; 2, Chimney Caps; 3, Mt. LeConte, Beartrap bald; 4, Mt. LeConte, Rocky Spur bald; 5, Mt. LeConte, Alum Cave balds; 6, Walker Prong balds.

4,000 Feet, Approximate Altitude—1, Brushy mountain, Taterhill lead bald; 2, Brushy mountain, First lead bald; 3, Brushy mountain, Second lead bald; 4, Ball mountain; 5, Mt. LeConte, Bullhead bald.

In Table II the seventeen balds studied are grouped into three sections according to their approximate altitudes. The woody species are arranged in sequence which approximates their "constancy" in the balds. Braun-Blanquet and Pavillard, in their "Vocabulaire de Sociologie Vegetale" (1), make the following statement about constance: "La CONSTANCE est une expression relative de la Presence, rapportee a des aires-eschantillons de dimensions determinees, mais assez grandes, prelevees une seule fois dans chaque individu d'association. En combinant les resultats des determinations de frequence avec ceux de la Constance, on obtient une expression synthetique de la repartition plus our moins uniforme des especes dans l'ensemble des individus d'association, c'est-a-dire une expression plus ou moins approximative de l'homogeneite de l'association." As a consequence, it is seen that only two species, *Rhododendron catawbiense* and *Vaccinium corymbosum,* are 100 per cent constant in that they occur in all seventeen

TABLE II

Woody Species	Approximate Altitude 6,500 Feet 1	2	3	4	5	6	5,000 Feet 1	2	3	4	5	6	4,000 Feet 1	2	3	4	5
Rhododendron catawbiense	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Vaccinium corymbosum	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Rhododendron punctatum	x	x	x	x	x	x	x	x	x	x	x	x	..	..	..	..	..
Dendrium prostratum	x	..	x	x	..	x	x	x	x	x	x	x	..	..	..	..	..
Vaccinium erythrocarpum	x	x	x	x	x	x	..	x	..	..	x	x	..	..	..	..	..
Menziesia pilosa	x	x	x	..	..	x	..	..	..	..	..	..	..	..	..	..	..
Pyrus americana	x	x	x	x	..	..	..	..	..	..	..	..	..	..	..	..	..
Prunus pennsylvanica	x	x	..	..	..	x	..	..	..	..	..	..	..	..	..	..	..
Picea rubra	x	..	..	x	x	x	..	..	..	..	..	..	..	..	..	..	..
Abies fraseri	x	..	..	x	x	x	..	..	..	..	..	..	..	..	..	..	..
Ribes prostratum	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Rubus canadensis	..	x	x	..	..	..	..	x	..	x	x	..	..	..	..	x	..
Diervilla sessilifolia	..	..	x	..	..	..	..	x	..	x	..	..	..	..	..	..	..
Kalmia latifolia	..	..	..	..	..	..	x	x	x	x	x	x	x	x	x	x	x
Pyrus melanocarpa	..	..	..	..	x	..	x	..	x	..	x	x	x	..	..	..	x
Lyonia ligustrina	..	..	..	..	..	..	x	..	..	x	..	..	..	..	..	..	x
Gaylussacia baccata	..	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..	x
Nyssa sylvatica	..	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..	x
Ilex monticola	..	..	..	..	..	..	..	x	x	x	..	x	x	x	x	x	x
Clethra acuminata	..	..	..	..	..	..	x	..	x	..	x	x	x	x	x	x	x
Viburnum cassinoides	..	..	..	..	..	..	x	..	x	..	x	x	..	x	..	x	x
Smilax rotundifolia	..	..	..	..	..	..	x	..	..	..	..	..	x	x	x	x	x
Acer rubrum	..	..	..	..	..	..	x	..	x	..	x	..	..	x	x	x	x
Robinia pseudo-acacia	..	..	..	..	..	..	..	..	x	..	..	..	..	..	..	..	x
Andromeda floribunda	..	..	..	..	..	..	..	..	..	x	x	..	..	..	..	x	x
Amelanchier canadensis	..	..	..	..	..	..	x	..	x	..	..	..	..	x	x	x	x
Rhododendron maximum	..	..	..	..	..	..	x	..	..	..	..	..	x	x	x	x	x
Leucothoe catesbæi	..	..	..	..	..	..	x	..	..	..	..	..	x	x	..	..	..
Oxydendrum arboreum	..	..	..	..	..	..	x	..	..	..	..	..	..	..	x	x	..
Pinus pungens	..	..	..	..	..	..	..	..	..	..	..	x	..	x	x	..	x
Sassafras variifolium	..	..	..	..	..	..	..	..	..	..	..	..	..	x	..	..	x
Gaylussacia ursina	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x
Gastanea dentata	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x
Hamamelis virginiana	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x
Number of species in each bald	10	8	10	8	7	9	16	7	12	10	12	11	10	14	12	14	22
Average number of species			9							11					14		

examples of the heath bald association. *Kalmia latifolia* is found to be present in all examples of the heath balds at the two lower levels.

The three altitudinal groups are more or less natural and distinguishable on a basis of their species. The highest group of balds, however, is more sharply distinguished than those at 5,000 and 4,000 feet elevation. The group at the highest altitude can be said to be distinguished by the presence of species from the adjacent spruce-fir forests, as *Menziesia pilosa, Pyrus americana, Prunus pennsylvanica, Ribes prostratum* and *Abies fraseri* and *Picea rubra.* The group at 5,000 feet altitude can be distinguished by the presence of *Rhododendron punctatum* and *Dendrium prostratum,* in addition to *Kalmia latifolia,* which is usually one of the dominants. The lower group of balds also has *Kalmia latifolia* as one of the dominants, but *Rhododendron punctatum* and *Dendrium prostratum* are missing.

There are other characteristics which help to distinguish the various aspects of the heath balds, such as degree of raw peat formation, presence of Sphagnum, etc., which will be taken up elsewhere.

The relatively greater importance of certain species in the various examples of the heath bald is indicated in the tabulation by the boldface "**x**." They may be considered as the "dominants," although the conclusion is based in most of the cases upon observation without the aid of statistical procedure. Certain of the species deserve special comment. For example, the presence of *Abies* and *Picea* in the heath balds is without successional significance in most, if not all cases. Occasional seedlings are able to establish and grow for a number of years, in fact, sometimes until their tops exceed the height of the shrub vegetation, at which time they are very quickly top-killed, if not completely eliminated. In fact, very few seedlings are able to establish in the heath balds in the first place. The random appearance of certain tree species at lower elevations might also be misleading, as *Robinia pseudo-acacia, Oxydendrum arboreum, Pinus pungens, Castanea dentata* and *Hamamelis virginiana.* They are of insufficient importance, however, to indicate the replacement of heath bald associations by trees, except possibly in the case of Bullhead bald. At the present it can be said that the heath balds, at both low and high altitudes, are probably derived from forested types by the elimination of the trees and that they are maintaining themselves as treeless areas of the broad-sclerophyll-scrub type. In other words, they are post-climax "islands" in the contiguous coniferous and broad-leaf formations. This matter is to be considered in more detail elsewhere.

Statistical Studies: Life-form Classes

The use of life-form concepts in plant geography has received a great impetus since the introduction of Raunkiaer's life-form classes and biological spectrum. When the flora of a region of sufficient size, or of a formation or association, is classified according to Raunkiaer's standard groups and percentages are determined, there results a "spectrum" which can be compared with the normal spectrum, a more or less arbitrary standard. Deviations from the arbitrary "normal" in the major groups characterize climatic formations, while minor differences within types of vegetation, for example the temperate deciduous forest, are also discernable.

In his 1908 paper (see Smith 18), Raunkiaer used the following classes based on the degree of protection afforded the perennating bud:

I. Phanerophytes (woody plants): (MM) Meso- and Megaphanerophytes (from 8 to 30 meters and over 30 meters in height); (M) Microphanerophytes (from 2 to 8 meters in height); (N) Nanophanerophytes (from 25 cm to 2 meters high).
II. (Ch) Chamæphytes (creeping or rosette plants with the perennating buds on the surface or not more than 25 cm above the soil).
III. (H) Hemicryptophytes (herbaceous, with dormant buds in the surface of the ground).
IV. Cryptophytes: (G) Geophytes (buds subterranean); (HH) Helophytes and Hydrophytes (aquatic species with buds in the muck or water).
V. (Th) Therophytes (annuals: buds in the seed).
VI. (E) Epiphytes.
VII. (S) Stem Succulents.

Raunkiaer's normal spectrum contains the following percentages for each class:

MM	M	N	Ch	H	G	HH	Th	E	S
6	17	20	9	27	3	1	13	3	1

Illustrations of the use of life-form classes could be added but are not necessary, since it is quite generally recognized that the type of spectrum of a region is an indication of the climatic conditions. To quote from Miss Ennis (6), who has done the best piece of work in America along this line: "The life-forms of the plants in the flora of a region present a definite response to the climate of that region."

The following table and summary (Table III) present the flora of the heath balds of the Great Smoky mountains according to their life-form classes. The most conspicuous feature is the high percentage of phanerophytes of two classes, namely, nanophanerophytes, 22.2 per cent, and microphanerophytes, 48.1 per cent, making a total of 70 per cent, as against 37 per cent in the normal spectrum for the same height

TABLE III

Life-Form Classes of the Heath Bald Flora

Flora	M	N	Ch	H	G	Th
Pteris aquilina					x	
Aspidium spinulosum intermedium				x		
Dicksonia punctilobula				x		
Osmunda cinnamomea					x	
Lycopodium complanatum				x		
Pinus pungens		x				
Picea rubra	x	x				
Abies fraseri	x	x				
Trillium undulatum					x	
Smilax rotundifolia	x	x				
Habenaria ciliaris					x	
Castanea dentata	x	x				
Magnolia fraseri	x	x				
Sassafras variifolium	x	x				
Saxifraga leucanthemifolia				x		
Ribes prostratum		x				
Hamamelis virginiana	x	x				
Pyrus americana	x	x				
P. melanocarpa	x	x				
Amelanchier canadensis	x	x				
Geum peckii				x		
Rubus canadensis		x				
Prunus pennsylvanica	x	x				
Robinia pseudo-acacia	x	x				
Rhus copallina	x	x				
Ilex monticola	x	x				
Acer rubrum	x	x				
Nyssa sylvatica	x	x				
Clethra acuminata	x	x				
Monotropa uniflora					x	
Rhododendron maximum	x	x				
R. catawbiense	x	x				
R. punctatum		x				
Menziesia pilosa		x				
Dendrium prostratum		x				
Kalmia latifolia	x	x				
Leucothoe catesbæi		x				
Andromeda floribunda	x	x				
Lyonia ligustrina		x				
Oxydendrum arboreum	x	x				
Epigæa repens			x			
Gaultheria procumbens			x			
Gaylussacia ursina		x				
G. baccata		x				
Vaccinium arboreum	x	x				
V. corymbosum	x	x				
V. corymbosum pallidum	x	x				
V. erythrocarpum		x				
Galax aphylla				x		
Gentiana linearis				x		
Melampyrum lineare						x
Diervilla sessilifolia		x				
Viburnum cassinoides	x	x				
Solidago glomerata				x		

TABULATION

Life-Form Classes	No. Species	Per Cent Heath Bald		Per Cent Normal Spectrum	
Phanerophytes					
Microphanerophyte (M)	26	48.1		17	
Nanophanerophyte (N)	12	22.2	70.4	20	37
Chamæphyte (Ch)	2	3.7		9	
Hemicryptophyte (H)	8	14.8		27	
Cryptophyte					
Geophyte (G)	5	9.2		3	
Therophytes (Th)	1	1.9		13	
	54	99.9		—	

classes of phanerophytes. Therophytes are conspicuously low in number, while the other classes are also low or absent in sufficient extent to account for the excess of low-growing phanerophytes. Many of the microphanerophytes fall into the nanophanerophyte class, if considered only from the lower altitudes.

As Fuller and Bakke (9) point out, "Ecology is one of the most difficult branches of botany when one attempts to measure or estimate with exactness the value of a single character and thus determine its significance, not from any specific peculiarity but because it embraces all the relations and the difficulties of botany taken as a whole." Thus it must be considered an important advance that plant geographers and ecologists have attempted statistical methods of vegetation analysis. In a comparison of different types of vegetation, one of the conspicuous variables, relatively easy to measure, is leaf size. Raunkiaer has selected, as a result of considering a large number of species, six leaf-size classes, which he maintains are more or less natural. The use of these leaf-size classes enables a more accurate description than words alone could convey in an analysis of a piece of vegetation. The limits of the six classes are set as follows:

1. Leptophyll (Le), 25 sq. mm. or less. 2. Nanophyll (Na), 9 x 25 sq. mm.—equals 225 sq. mm. 3. Microphyll (Mi), 9^2 x 25 sq. mm.—equals 2,025 sq. mm. 4. Mesophyll (Me), 9^3 x 25 sq. mm.—equals 18,225 sq. mm. 5. Macrophyll (Ma), 9^4 x 25 sq. mm.—equals 164,025 sq. mm. 6. Megaphyll (Mg), larger than macrophyll.

Scale drawings of these leaf-size classes are to be found in the paper by Fuller and Bakke (9) and can be used in determining the proper leaf-size class of any species, and is of considerable utility, since the above figures, in the abstract, do not convey any idea of the actual size.

The first step in leaf-size classification involves separation of the species on the following bases, after which the percentages of each leaf-size class are computed for each group. Group 1—Deciduous: species with simple and lobed leaves. Group 2—Deciduous: species with lacerated and decompound leaves. Group 3—Evergreen species. Group 4—Aphyllous species.

The following table and summary present (Table IV) the data for the complete heath bald flora according to the system described. In addition those that are woody species are indicated.

The table of leaf-size classes is sufficiently clear and detailed to obviate any lengthy discussion of the factors involved. Eight species are ericaceous, falling into the following description, *evergreen-broad-leaved-microphylls,* which includes the dominants of the flora except

TABLE IV

Flora	Aphyllous	Coniferous	Evergreen Broad Le	Evergreen Broad Na	Evergreen Broad Mi	Evergreen Broad Me	Deciduous Simple Le	Deciduous Simple Na	Deciduous Simple Mi	Deciduous Simple Me	Deciduous Simple Ma	Deciduous Pinnate Le	Deciduous Pinnate Na	Deciduous Pinnate Mi	Woody
Pteris aquilina	..	..	..	..	..	..	..	..	..	..	..	..	x	..	..
Aspidium spinulosum intermedium	..	..	..	..	..	..	..	..	..	..	..	x	..	..	..
Dicksonia punctilobula	..	..	..	..	..	..	..	..	..	..	..	x	..	..	..
Osmunda cinnamomea	..	..	..	..	..	..	..	..	..	..	..	..	x	..	..
Lycopodium complanatum	..	x*	..	..	..	..	..	..	..	..	..	..	..	..	..
Pinus pungens	..	x	..	..	..	..	..	..	..	..	..	..	..	..	x
Picea rubra	..	x	..	..	..	..	..	..	..	..	..	..	..	..	x
Abies fraseri	..	x	..	..	..	..	..	..	..	..	..	..	..	..	x
Trillium undulatum	..	..	..	..	..	..	..	..	..	x	..	..	..	..	..
Smilax rotundifolia	..	..	..	..	..	..	..	..	x	..	..	..	..	..	x
Habenaria ciliaris	..	..	..	..	..	..	..	..	x	..	..	..	..	..	..
Castanea dentata	..	..	..	..	..	..	..	..	..	x	..	..	..	..	x
Magnolia fraseri	..	..	..	..	..	..	..	..	..	..	x	..	..	..	x
Sassafras variifolium	..	..	..	..	..	..	..	..	x	..	..	..	..	..	x
Saxifraga leucanthemifolia	..	..	..	..	..	..	..	..	x	..	..	..	..	..	..
Ribes prostratum	..	..	..	..	..	..	..	..	x	..	..	..	..	..	x
Hamamelis virginiana	..	..	..	..	..	..	..	..	x	..	..	..	..	..	x
Pyrus americana	..	..	..	..	..	..	..	..	..	..	..	..	..	x	x
P. melanocarpa	..	..	..	..	..	..	..	..	x	..	..	..	..	..	x
Amelanchier canadensis	..	..	..	..	..	..	..	..	x	..	..	..	..	..	x
Geum peckii	..	..	..	..	..	..	..	..	x	..	..	..	..	..	..
Rubus canadensis	..	..	..	..	..	..	..	..	..	..	..	..	..	x	x
Prunus pennsylvanica	..	..	..	..	..	..	..	..	x	..	..	..	..	..	x
Robinia pseudo-acacia	..	..	..	..	..	..	..	..	..	..	..	..	x	..	x
Rhus copallina	..	..	..	..	..	..	..	..	..	..	..	..	..	x	x
Ilex monticola	..	..	..	..	..	..	..	..	x	..	..	..	..	..	x
Acer rubrum	..	..	..	..	..	..	..	..	..	x	..	..	..	..	x
Nyssa sylvatica	..	..	..	..	..	..	..	..	x	..	..	..	..	..	x
Clethra acuminata	..	..	..	..	..	..	..	..	..	x	..	..	..	..	x
Monotropa uniflora	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Rhododendron maximum	..	..	..	..	..	x	..	..	..	..	..	..	..	..	x
R. catawbiense	..	..	..	..	x	..	..	..	..	..	..	..	..	..	x
R. punctatum	..	..	..	..	x	..	..	..	..	..	..	..	..	..	x
Menziesia pilosa	..	..	..	..	..	..	..	x	..	..	..	..	..	..	x
Dendrium prostratum	..	..	x	..	..	..	..	..	..	..	..	..	..	..	x
Kalmia latifolia	..	..	..	..	x	..	..	..	..	..	..	..	..	..	x
Leucothœ catesæi	..	..	..	..	x	..	..	..	..	..	..	..	..	..	x
Andromeda floribunda	..	..	..	..	x	..	..	..	..	..	..	..	..	..	x
Lyonia ligustrina	..	..	..	..	..	..	..	..	x	..	..	..	..	..	x
Oxydendrum arboreum	..	..	..	..	..	..	..	..	..	x	..	..	..	..	x
Epigæa repens	..	..	..	..	x	..	..	..	..	..	..	..	..	..	x
Gaultheria procumbens	..	..	..	..	x	..	..	..	..	..	..	..	..	..	x
Gaylussacia ursina	..	..	..	..	..	..	..	..	x	..	..	..	..	..	x
G. baccata	..	..	..	..	..	..	..	x	..	..	..	..	..	..	x
Vaccinium arboreum	..	..	..	..	..	..	..	..	x	..	..	..	..	..	x
V. corymbosum	..	..	..	..	..	..	..	..	x	..	..	..	..	..	x
V. corymbosum pallidum	..	..	..	..	..	..	..	..	x	..	..	..	..	..	x
V. erythrocarpum	..	..	..	..	..	..	..	..	x	..	..	..	..	..	x

Flora	Aphyllous	Coniferous	Evergreen Broad Le	Evergreen Broad Na	Evergreen Broad Mi	Evergreen Broad Me	Deciduous Simple Le	Deciduous Simple Na	Deciduous Simple Mi	Deciduous Simple Me	Deciduous Simple Ma	Deciduous Pinnate Le	Deciduous Pinnate Na	Deciduous Pinnate Mi	Woody
Galax aphylla	..	..	..	..	x	..	..	..	..	..	..	..	..	..	..
Gentiana linearis	..	..	..	..	..	..	..	..	x	..	..	..	..	..	..
Melampyrum lineare	..	..	..	..	..	..	..	x	..	..	..	..	..	..	..
Diervilla sessilifolia	..	..	..	..	..	..	..	..	x	..	..	..	..	..	x
Viburnum cassinoides	..	..	..	..	..	..	..	..	x	..	..	..	..	..	x
Solidago glomerata	..	..	..	..	..	..	..	..	x	..	..	..	..	..	..

TABLE V

Summary of Leaf-Size Class Data

Classification	Total Flora No. Sp.	Total Flora Per Cent	Woody Flora No.	Woody Flora Per Cent	Ericales No. Species	Ericales Dominants
Aphyllous	1	2	....	....	1	....
Evergreen	14	26	12	30	10	5
Scale-leaved	1	....	....	....	....	....
Needle-leaved	3	....	3	....	....	....
Broad-leaved	10	19	9	23	10	5
Leptophyll	1	....	1	....	....	1
Nanophyll	0	....	....	....	....	....
Microphyll	8	15	7	18	8	3
Mesophyll	1	....	1	....	1	1
Deciduous	39	72	28	70	10	1
Simple	31	57	24	60	10	1
Leptophyll	0	....	....	....	....	....
Nanophyll	3	....	2	....	2	....
Microphyll	22	41	17	42	6	1
Mesophyll	5	....	4	....	2	....
Macrophyll	1	....	1	....	....	....
Pinnately compound	8	15	4	10	....	....
Leptophyll	2	....	....	....	....	....
Nanophyll	3	....	1	....	....	....
Microphyll	3	....	3	....	....	....
Woody species	40	74	40	....	20	....
Herbaceous	14	26	....	....	1	....

for Vaccinium. Such a physiognomy has been described as "broad-sclerophyll scrub" by Cooper (4). This form is fairly common in two types of situations: mild temperate districts with winter rain and prolonged summer drought, and cool humid regions. In respect to the first type of situation, the regions which possess such a climate and support such a vegetation are, according to Schimper (17), the Mediterranean shores, the southwest extremity of Africa, southwestern and much of southern Australia, central Chile and California. The second type develops in regions of high humidity, where even in summer heavy mists arise daily or almost daily. . . . The leaves belong to the laurel-form, that is to say, they are undivided, entire and coriaceous. To the latter the heath-scrub communities of the Great Smoky mountains must be assigned.

Since most of the species characteristic of the heath balds are found also in the contiguous forests, it is important to bring out the fact that the open nature and exposure of the bald situations result in a considerable change of leaf-size, when the heath bald is contrasted with the spruce-fir forest, for identical species. This is brought out in the following table (VI), where the average size, and maximum ranges are presented for 100 representative leaves of each of seven species. Half of the leaves were taken from bald situations and half from nearby plants growing under the protection of the forest. The leaves for *Rhododendron maximum, Kalmia latifolia* and *Lyonia ligustrina* are from the bald on Brushy mountain at approximately 5,000 feet elevation. The remaining species are from the balds on Mt. LeConte at an elevation of about 6,500 feet. In each instance the more mesophytic forms are from close by, at somewhat lower elevations.

In addition to a decrease in the average size of the leaf blades, there are other changes of xeromorphic character: (1) leaf margins are revolute (sometimes *Rhododendron catawbiense* leaves are incurled until their margins meet); (2) leaves are likely to be more hairy or scurfy than under the trees; color is darker, and (4) the petioles and branches are stouter and shorter.

The following table gives the data as to dimensions. The average length and width of a leaf is frequently about half in the balds of that in the forest. In the instance of *Rhododendron catawbiense* and *Menziesia pilosa,* the difference is such as to change the species from one leaf-size class to the next one smaller.

STATISTICAL STUDIES: QUADRAT STUDIES

Brushy mountain heath bald, 5,000 feet elevation, was selected for quadrat studies because of its extensive development and intermediate altitudinal position. Kenoyer (11) has made a study of Raunkiaer's so-called "Law of Frequence" on American vegetation and found the principle sound. The main differences between Raunkiaer's and Kenoyer's ratios of frequency classes seem to be a result of American plant associations being generally richer in species. Translating Braun-Blanquet and Pavillard (1) we have the following definition of frequency:

TABLE VI

Comparison of Leaf Sizes (Blades) of Some Ericads Grown in Heath Balds and Under Protection of Forest

(Each measurement is based on 50 representative leaves.)

Name of Plant	Length in cm. Mesophyte Woodland	Length in cm. Xerophyte Bald	Width in cm. Mesophyte Woodland	Width in cm. Xerophyte Bald
Rhododendron maximum (Mesophyll)				
Largest dimension	26.4	16.2	8.6	5.4
Smallest dimension	15.1	6.8	4.9	2.2
Average dimension	20.71	11.38	6.69	3.58
Rhododendron catawbiense (Microphyll and Mesophyll)				
Largest dimension	18.5	10.5	7.1	4.3
Smallest dimension	8.1	3.6	3.7	1.5
Average dimension	13.53	6.90	5.90	2.97
Rhododendron punctatum (Microphyll)				
Largest dimension	11.2	6.9	3.9	3.3
Smallest dimension	4.0	2.5	1.2	1.0
Average dimension	8.21	4.20	2.81	1.80
Menziesia pilosa (Nanophyll and Microphyll)				
Largest dimension	6.7	3.1	2.8	1.7
Smallest dimension	1.5	1.2	0.7	0.6
Average dimension	4.34	2.03	1.91	1.52
Vaccinium erythrocarpum (Microphyll)				
Largest dimension	7.5	6.3	2.7	2.5
Smallest dimension	1.6	0.8	1.5	0.6
Average dimension	5.34	4.01	1.86	1.68
Kalmia latifolia (Microphyll)				
Largest dimension	10.5	4.8	4.1	2.2
Smallest dimension	2.9	1.6	1.2	0.6
Average dimension	7.26	3.60	3.03	1.47
Lyonia ligustrina (Microphyll)				
Largest dimension	6.9	5.7	3.7	3.8
Smallest dimension	3.0	2.8	1.6	1.0
Average dimension	5.16	4.07	2.85	2.13

"Frequency is a statistical expression derived by preparing complete floristic lists of a certain number of sample areas (quadrats) of equal dimension, disseminated as much as possible throughout the extent of the individual example of the association." The information so derived is usually handled as follows: the frequency of a species in an association is the relation expressed in per cent between the number of quadrats which contained it and the total number of quadrats analyzed in the particular association. As a matter of convenience, the percentages are usually divided into five classes, as follows: Class A, species with 1-20 per cent frequence; Class B, species with 21-40 per cent frequence; Class C, species with 41-60 per cent frequence; Class D, species with 61-80 per cent frequence; Class E, species with 81-100 per cent frequence.

It will then be found that a certain percentage of the total number of species encountered in the association will fall into Class A, Class B, etc., with Class A greater than B, B larger than C, C larger than D, but with E larger than D, as follows: A > B > C > D < E.

Raunkiaer and Kenoyer found numerical values for the classes as follows:

TABLE VII

Author	Vegetation and No. of Percentages Involved	Per Cent. in Frequency Classes A	B	C	D	E
Raunkiaer	European 8,087%	53	14	9	8	16
Kenoyer	American 1,425%	69	12	6	4	9

Furthermore, Kenoyer (11) established the valuable fact that twenty-five quadrats of sufficient size, widely distributed in an homogeneous association, are sufficient for a statistical analysis of frequency. Romell (16) emphasizes that "statistics made with different sizes of sample areas cannot be compared." The commonest quadrat sizes are 0.1 m, 1 m, and 10 m on a side. In studying various associations in the Great Smoky mountains, 1-meter quadrats have been used exclusively. The results of two series of twenty-five quadrats are expressed in the following tables (VIII and IX).

The presence of a species in a quadrat is indicated by a number which stands for the coverage class of the species, and is termed "dominance" by Braun-Blanquet and Pavillard. They say: "Dominance concerns the extent, volume and surface, occupied or covered by the individuals of each species." In many-layered groups it must be evaluated separately for each stratum. As in the case of frequence, five classes are used in expressing degree of dominance. Class 1—1-5 per cent coverage; Class 2—6-25 per cent coverage; Class 3—26-50 per cent coverage; Class 4—51-75 per cent coverage; Class 5—76-100 per cent coverage.

When several species are present in one quadrat and dominance figures (classes) are given each which total more than 5, it is to be under-

TABLE VIII

Brushy Mountain Heath Bald—In Area of First and Second Burn, 1929

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Pct.
	25 Quadrats: Numbers = Coverage																									
Acer rubrum	..	..	..	..	..	..	..	..	..	..	..	..	..	2	..	..	..	..	..	..	..	..	..	..	..	4
Amelanchier canadensis	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	2	..	..	..	..	..	..	..	..	..	4
Clethra acuminata	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	4
Dendrium prostratum	3	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	1	..	12
Galax aphylla	1	1	1	..	..	2	..	..	..	..	..	1	..	..	..	..	..	1	..	..	1	..	..	..	1	32
Gaultheria procumbens	..	5	1	2	..	..	1	1	..	1	..	2	..	1	1	..	..	..	..	..	..	1	..	..	..	40
Gaylussacia baccata	2	..	3	..	2	3	..	..	..	..	..	..	..	..	1	..	..	3	..	..	3	..	..	..	1	32
Ilex monticola	..	..	..	..	..	..	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	4
Kalmia latifolia	2	1	3	3	3	2	3	4	1	1	2	1	2	..	..	..	3	1	2	1	1	2	1	4	2	88
Lyonia ligustrina	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	4
Osmunda cinnamomea	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	2	..	..	..	4
Picea rubra (Top dead)	..	..	..	..	..	..	..	..	..	..	..	..	5	..	..	..	..	..	..	..	..	..	..	..	..	4
Pteris aquilina	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	4
Pyrus melanocarpa	..	..	..	..	..	..	..	..	..	..	..	3	..	1	..	..	..	..	..	2	..	..	..	..	..	12
Rhododendron catawbiense	1	1	2	1	4	2	1	1	5	2	4	..	..	3	2	1	3	2	2	..	2	..	4	1	3	84
Smilax rotundifolia	..	..	..	..	..	..	..	..	1	..	..	..	..	..	1	..	..	..	1	..	..	..	..	..	..	12
Vaccinium corymbosum (?)	..	..	..	1	..	..	2	1	..	..	1	..	..	2	3	3	1	..	..	2	..	1	..	1	..	44
Viburnum cassinoides	..	1	..	1	..	..	1	..	..	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	16
Number of species (18)	5	5	5	5	3	4	6	4	3	4	3	4	2	5	5	4	3	4	4	4	5	4	2	4	4	....

Frequency Classes A > B > C > D < E = 67-17-5-0-11

TABLE IX

Brushy Mountain Heath Bald—In Area of Most Recent Burn, Taken 1930

Species	25 Quadrats: Numbers = Coverage																									
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Pct.
Clethra acuminata	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	4
Dendrium prostratum	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	1	..	..	..	..	8
Epigæa repens	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	3	..	1	..	..	..	..	..	..	..	8
Galax aphylla	..	..	..	2	..	..	..	2	..	2	2	2	2	..	..	2	2	..	..	1	1	1	..	1	1	52
Gaultheria procumbens	4	1	4	2	2	2	3	3	4	1	2	3	3	5	4	2	2	2	1	1	..	2	3	2	2	96
Gaylussacia baccata	2	1	4	1	2	3	2	1	..	..	2	4	2	2	2	3	2	3	2	4	2	2	3	3	2	92
Kalmia latifolia	3	2	..	2	2	2	3	4	3	4	3	2	2	5	3	..	3	..	4	..	2	2	1	3	2	84
Lycopodium obscurum	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	4
Lyonia ligustrina	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	4
Medeola virginiana	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	4
Melampyrum lineare	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	1	..	2	..	..	..	2	..	1	20
Pteris aquilina	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	2	..	..	4
Pyrus melanocarpa	1	1	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	2	2	..	1	..	1	28
Rhododendron catawbiense	1	4	3	5	1	..	..	1	3	..	..	..	2	..	..	2	1	..	1	2	..	..	..	..	2	52
Smilax rotundifolia	..	..	1	..	..	1	..	..	1	..	1	1	..	2	..	1	..	..	..	1	..	..	..	..	2	36
Vaccinium corymbosum (?)	3	2	1	..	..	2	..	..	..	..	..	..	..	..	..	2	3	1	..	2	..	..	..	..	1	36
Number of species (16)	7	6	5	5	4	5	3	5	5	3	5	5	6	4	3	7	8	4	6	8	5	4	6	4	10	....

Frequency Classes A > B > C > D < E = 50-19-12-0-19 stood that lower shrubs or herbs, like Dendrium, Galax, Gaultheria, etc., are underneath Kalmia, Vaccinium and Rhododendron, and thus have overlapping coverage. The twenty-five quadrats analyzed in 1930 in the area of the most recent burn (several years ago), indicate a relative importance of *Gaylussacia baccata* and *Gaultheria procumbens* 92 per cent and 96 per cent frequency, which has dropped off in the areas of the older burns, where they enjoy frequency of 32 and 40, respectively. *Kalmia latifolia* and *Rhododendron catawbiense* have about the same frequence in both areas. These species are to be considered most important in the association on Brushy mountain.

FACTORS IN INITIATION, MAINTENANCE AND DISTRIBUTION OF HEATH BALDS

Climatic Factors.—In the absence of quantitative weather data in the vicinity of the Great Smoky mountains, one has to depend on fragmentary field data and general observations. In the region of the heath balds the climate can be briefly described as "oceanic" despite the inland location. Rainfall and relative humidity are high, while the temperature tends to be low, but subject to fluctuations. Evaporation, as measured by the Livingston atmometers, is generally quite low.

Rainfall in the higher regions is said to exceed 80 inches a year, a contention well substantiated by a comparison of the vegetation of the Smoky mountains with regions of high rainfall in North Carolina where records have been kept: at Mt. Mitchell near Asheville, and in the southern Blue Ridge mountains at Highlands, North Carolina. In respect to the humidity, it is apparent that the development of heath balds is closely related to upper altitudes almost constantly enveloped by clouds, especially during summer months.

Temperatures are generally low and equable (see Table XIII), yet 90 degrees Fahrenheit was frequently reached in the abnormal summer of 1930. The winters may frequently have short periods as cold as 18 degrees below zero, as in December, 1928. It is in the winter periods, with frost, sleet, high winds and sudden and extreme drops in temperature, that the exposed situations of the heath balds, which are generally without the protection of deep snow, present the greatest demands on the heath bald species. Otto Stocker (20 and 21), dealing with the problem of xeromorphy of heath and bog plants, proposes that they should be considered as "anemorphs," since, as he says, "the leaf structure of the Ericaceæ seems to be an adaptation to the very heavy winter storms of heath and bog regions rather than to decreased transpiration."

In the summer the climatic conditions in the Great Smoky mountains do not seem to be particularly important in the maintenance of the heath balds. In this connection, see the following evaporation rates from Livingston (12) atmometers for midsummer periods in 1928 and 1929, Tables X and XI. Station A was located in what seemed to be a representative situation in Maintop heath bald, Mt. LeConte. The spruce-fir station, C, was in a pole stand north of the spring about one-fourth mile distant from A but at almost the same elevation. In this sort of place the ericads are relatively unimportant. Station B was considered transitional because of the heavy development of ericads under the fir. Atmometers were maintained in pairs at all stations and were frequently checked for working order, especially as to the Thone rain valves, which were, of course, absolutely necessary in such a rainy region. The 1928 data represent evaporation rates for a "wet" season, while the 1929 records are probably more nearly average. Since the evaporating power of the air is so very low, we may well be curious as to the availability of water to the plant. Stocker (20 and 21), Thatcher (22) and others have shown the transpiration rates of heath and moor plants place them more nearly with mesophytes than with xerophytes, and that the peat substratum cannot be considered "physiologically dry." A recent discussion and summarization of work along this line is to be found in Maximov's (15) recent book on the relation of the plant to water.

TABLE X

Weekly Evaporation (Livingston Atmometers) Mt. LeConte, Altitude 6,500 Feet

Date, 1928 Week Ending	Heath Bald A	Transition B	Spruce-Fir C
7-7	60.5 cc	39 cc	15 cc
7-14	11	4.5	3
7-21	33	11	8
7-28	22	6	2
8-4	40.5	25.5	7.5
8-11	20	8	4
8-23*	27	9.5	4.5
9-5*	35.5	9.5	4.5
9-12	62.5	41.5	17
Average, by weekly periods	34.6 cc	16.3 cc	7.3 cc

*Figures given on a seven-day basis.

TABLE XI

Weekly Evaporation (Livingston Atmometers)

Date, 1929 Week Ending	Mt. LeConte, 6,600 Ft. Heath Bald A	Transition B	Spruce-Fir C	Brushy Mt., 5,000 Ft. Beech Gap D	Heath Bald E
8-20	104 cc	30 cc	16 cc	36 cc	95 cc
8-27	117	31	18	41	106
9- 3	61	18	11	23	65
9-10	43	15	9	20	52
9-17	73	29	14	35	87
9-24	93	35	17	38	96
Average weekly amount	82 cc	26 cc	14 cc	32 cc	83 cc

The following study, using *Rhododendron catawbiense,* reveals a more rapid transpiration rate on the part of the more "xeromorphic" leaves of plants growing in a peat substratum in a heath bald than by those growing close by, but under the protection of spruce-fir with little or no peat. On Maintop, Mt. LeConte, at an elevation of approximately 6,600 feet, two plants of *Rhododendron catawbiense* were selected for transpiration studies by the cobalt chloride method. Livingston clips (13) with standard color comparisons were used and the length of time required for the change from one color standard to another, on the part of the cobalt chloride paper, was taken to be an inverse measure of the transpiration rates.

One plant used in the study was located at the top of the Maintop heath bald, while the other was just over the crest not more than fifty feet away, but under the protection of the spruce-fir association (here mostly *Abies fraseri,* an endemic). Each leaf studied was about two feet above the ground and was the terminal one of the shoot. Each shoot bore about ten leaves. The two were as nearly comparable as possible. The plant in the bald showed the effect of the association and the environment in many respects: it was short (about four feet high), compact, with the leaves very much reduced and incurled.

The readings were made between three and four in the afternoon, August 9. The results are indicated in Table XII. The four readings for each leaf were made in the same spot, halfway between the midvein and the margin, near the middle of the leaf.

This single set of figures does not warrant any conclusion, yet it is in accord with the extensive observations of Thatcher (22) that heath plants growing in peat are capable of maintaining a high rate of transpiration when compared with soil and that the so-called xerophytic

TABLE XII

COMPARATIVE TRANSPIRATION RATES OF RHODODENDRON CATAWBIENSE

STATION	Air Temperature Near Leaf	Time for Change of Cobalt Paper	Time of Day
Heath bald	28 c	60 seconds	3:00 P.M.
	24.5 c	65 seconds	3:10 P.M.
	24 c	70 seconds	3:15 P.M.
	23 c	130 seconds	3:20 P.M.
Average		81 seconds	
Spruce-fir	22 c	240 seconds	3:35 P.M.
	21.5 c	225 seconds	3:40 P.M.
	21 c	275 seconds	3:45 P.M.
	20.5 c	320 seconds	3:55 P.M.
Average		285 seconds	

leaf structures do not necessarily reduce water loss on a unit area basis. The leaves of *Rhododendron catawbiense* grown in the heath bald are conspicuously smaller, thicker and incurled, *i. e.*, xeromorphic.

The two studies (Table XIII) on diurnal temperature ranges of soil and air in heath bald and spruce-fir show a good contrast in seasons. The 1928 season was cool, rainy and more nearly normal than the excessively warm and dry 1930 season. Each season is well illustrated by the days selected in August. Air temperatures increase and diminish more rapidly than soil temperatures and reach a higher maximum, except in the case of bare sand soil in the heath bald. The soil temperatures in all cases were taken by standard Tycos soil thermometers inserted in the surface peat (except A2, which was in sand) and undisturbed throughout the day. Air temperatures were derived from ordinary thermometers suspended about one foot above the soil. Each station was carefully selected so as to be representative of the vegetation. Consequently, it is seen that the spruce-fir association is very cool in midsummer and almost free from diurnal fluctuations either in air or soil temperatures. The conditions in the heath bald are much more variable, yet are not extreme, soil temperatures being remarkably low where there is a peat layer—and that is characteristic.

EDAPHIC FACTORS.—Since, with the exception of severe winter periods, climatic factors are not directly important in the formation of heath balds (note important secondary effects, however), we may well turn to a consideration of edaphic factors for further elucidation of the heath bald problem.

Upper south-facing slopes are frequently so consistently occupied

TABLE XIII

Air and Soil Temperatures in Heath Bald and Spruce-Fir

	Air Temperature			Soil Temperature			
	Heath Bald	Transition	Spruce-Fir	Heath Bald		Transition	Spruce-Fir
				Peat	Sand		
8-7-28	A	B	C	A1	A2	B	C
6- 6:30 A. M.	49F	49F	49F	56F	52F	54F	53F
8- 8:20	55	52.5	51	56	59	54	53
10-10:25	62.5	60	57.5	57	71	55	53
12-12:15	67.5	62	61	57	74	57	54
1:45-2:05	69	61	62	59	83	57	56
4- 4:10	61	59	57	60	74	57	55
7- 7:15	52	52	53.5	59	62	56	54
8-9-30							
7:15 A. M.	65F	....	61F	60F	....	....	53F
8:35	72.5	....	67	61	....	....	54
9:45	75	....	67	60	....	....	54
10:40	77	....	69.5	61.5	....	....	54.5
12:50	96	....	75	65	....	....	55
2:30	93	....	75	70	....	....	55
3:20	82.5	....	71	68	....	....	55
4:20	74	....	66	68	....	....	55
5:00	69	....	66	67	....	....	55

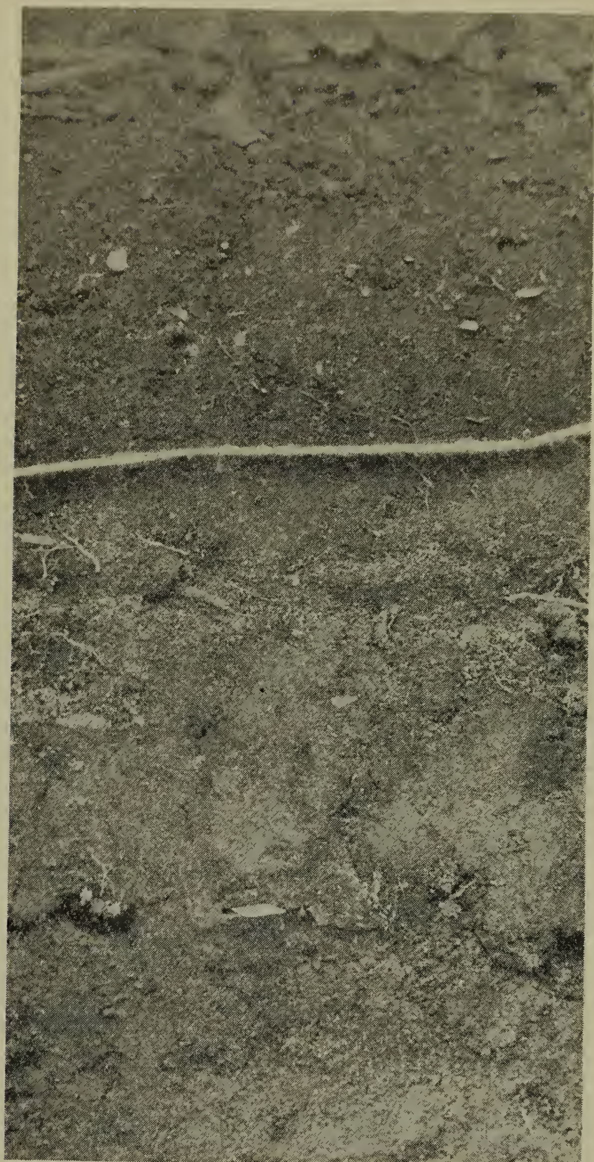
by heath balds, as in the tributary region of Roaring Fork, west of Brushy mountain, that one expects to find the answer to their distribution therein. It is not so simple a matter, however, as increased xerophytism of habitat due to southern exposure. The problem is further complicated by balds occurring elsewhere on all exposures, north, east and west, as well as south. Neither is the angle of slope a determining factor. On certain precipitous ridges, as the Chimney Caps, one would readily believe that trees can not hold on; and that may be partly true, but many slopes far exceeding 45 degrees in steepness are heavily forested, as in the Trout Creek and Alumn Cave region, while gentler slopes on Brushy mountain are bald. The relation of the slope and the heath bald position seems to be one of direction of prevailing winds. In a broad sense, the prevailing winds are from the southwest, but in the mountains they are variously deflected and the heath balds seem always to be on the windward side, a position of importance during the severe winter weather.

Certain characteristics of the soils of the heath balds, notably hydrogen-ion concentration and attendant factors, as peat formation, are considered elsewhere by the writer, Cain (2), but the matter of podsolization of the soil deserves special attention.

A podsolized soil is one with a gray leached layer in the profile which, strictly speaking, is termed the "podsol," from the Russian "sola," meaning ash. Recently, however, the term has been applied, not only to the leached layer, but to the whole soil profile and even to the process of development. There are essentially three regions which make up the podsol profile: (1) a raw humus layer on top, beneath which is, (2) the gray leached podsol region, and underneath this, (3) a brown enriched layer. Podsolization occurs to a certain extent in the soils of the hemlock, pine-heath and birch woods, but is especially characteristic of the soils of the spruce-fir and the heath bald regions.

The best development of the podsol type observed by the writer in the Great Smoky mountains is on the Brushy mountain heath bald, Table XIV. Figure 3 presents a photograph of one typical profile from Brushy mountain at an elevation of almost 5,000 feet. In this profile we are able to distinguish more than three layers. On the surface is a thin layer of dry peat (A 1) (Table XIV) which has been designated as "trochentorf" and has a wide distribution in heath balds at lower altitudes and in pine heath. Beneath this is found a considerable quantity of moist brown peat (A 2) in which the vegetative structure is well preserved. This layer gradually darkens downward into the brownish-black soil humus-layer (A 3). These first three layers of the organic horizon are extremely acid and provide the dissolving substances so important in the formation of the ash gray leached layer (A 4), the "podsol" layer. Beneath the A horizon is the enriched B horizon, ochre-yellow to deep brown in color. An unusually compact "ortsstein" layer is found at the top of the B horizon (B 1). This hardpan is a solidification of substances carried down by the percolation of dissolving substances from above and precipitated at the bottom of the leached zone (A 4). This particular ortsstein can be lifted out of the soil in large layers from 1/8 to 3/8 of an inch in thickness, so solid that they resemble iron concretions. Beneath the ortsstein is a layer (B 2) also enriched but uncemented and effectively cut off from the roots of the plants above by the iron pan. Lower down is the C horizon of "Muttergestein," or inorganic parent material.

The podsol type of soil development is considered in detail by Hans Jenny (10), who emphasizes the climatic relationships involved in its formation. Christopherson (3), in his studies on soil reaction in Sylene National Park, Norway, also arrives at the conclusion that climatic factors are of primary importance in podsol development, especially



Trochentorf

Brown fibrous peat

Black humus transition

Podsol, gray-leached zone

Ortsstein, iron hardpan

Enriched, burnt-sienna zone

Subsoil not shown

Figure 3. Podsol Profile from Brushy Mountain Heath Bald. The white line in the photograph is a string placed on the transition line from the peat layer to the gray-leached podsol.

TABLE XIV

Podsol Profile, Brushy Mountain Heath Bald

Horizon	Zone	Thickness	Name or Description
A	1	0.5 cm	Trochentorf
	2	8.0 cm	Brown fibrous peat
	3	2.0 cm	Black humus transition
	4	13.0 cm	Gray-leached podsol
B	1	0.5 cm	Ortsstein, iron hardpan
	2	15.0 cm	Enriched brown Zone
C	1	10.0 cm plus	Subsoil

precipitation and temperature. He says: "In a general way, a low average temperature with a high average precipitation are favorable for podsol development." Three recent papers on work done in eastern United States emphasize the importance of podsolization in silviculture, Fisher (7), Lutz (14) and Stickel (19). They confirm the importance of abundant rainfall and cool temperatures, especially severe winters, but add that podsol soils can also develop in regions with more favorable climate as a result of producing pure stands of timber, especially conifers. It is desirable to emphasize the wide development of the podsol type in associations dominated by broad-leaved evergreen species, as the Ericaceæ of these balds. The development of the podsol and ortsstein layers the writer believes to be particularly important in the heath bald associations, since the vegetative habits of the heath bald species fit them for existence in the podsolized soil. Their root systems are shallow and the plants spread horizontally by rhizomes. The result is a dense mat of interlocking roots in the A horizon of the soil, with few if any penetrating the ortsstein layer.

Catastrophic Factors.—There seem to be three catastrophic factors influencing the formation and maintenance of heath balds in the Great Smoky mountains; they are windfall, landslide and fire. Of these factors, fire is by far the most important.

The effect of repeated fires can be seen on Brushy mountain. The last three fires have burned successively smaller areas. Passing into the treeless area from Beech Gap, sometimes known as Grassy Gap, the trail goes under a thicket of Rhododendrons, Kalmia and other heath bald species eight to ten feet high, growing so dense that it is impossible to leave what was until recently only a bear trail except by cutting away the brush. In the area of the second burn the shrubs are four to five

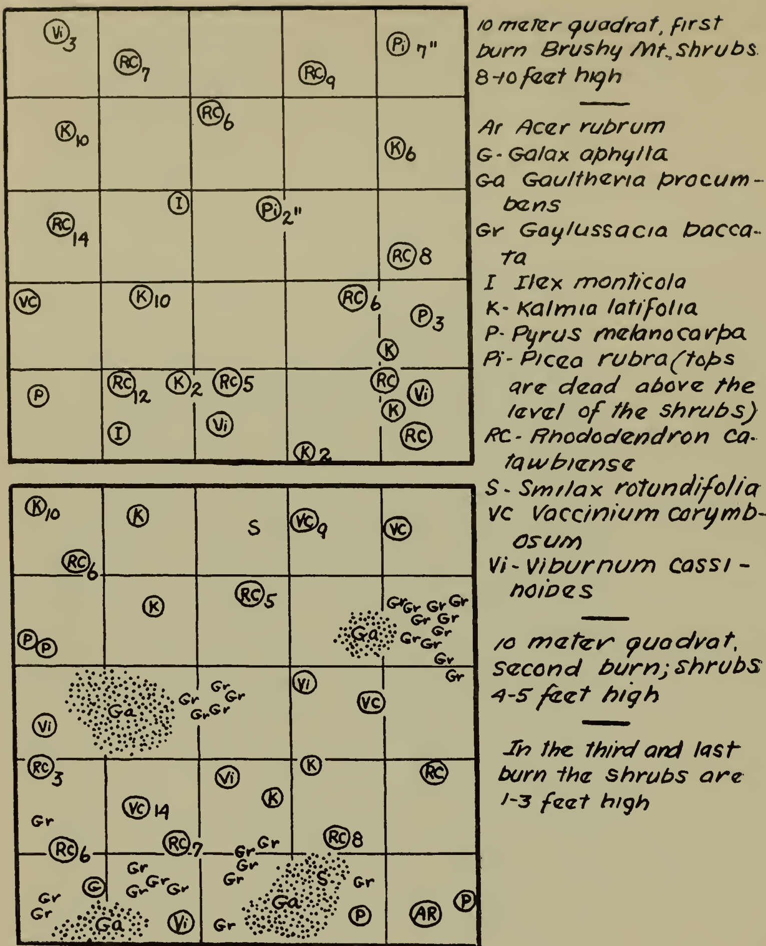


Figure 4. Two Ten-Meter Quadrats from the Oldest Burns on Bushy Mountain. For frequency studies of this bald, see Tables VIII and IX.

feet high, while nearer the center and top of the mountain, in the zone of the most recent fire, the shrubs are mainly two to three feet high. This change in the vegetation is indicated in the following quadrats, Fig. 4.

Some species, as *Kalmia latifolia, Rhododendron catawbiense* and *Vaccinium* spp. are particularly resistant to the repeated ravages of fire. Numerous sprouts an inch or less in diameter can be seen rising from gnarled balls of root stocks and old stem bases a foot or two in diameter which have withstood many fires and the destruction of aerial parts. Other species less characteristic of the balds, as *Acer rubrum, Prunus pennsylvanicum, Betula lenta* and *B. lutea,* frequently make a scattered appearance after fires, enjoy a rather enfeebled growth and succumb during the next conflagration if not before. The ericads are so resistant to fire and sprout back so readily that other species characteristic of the contiguous forests have little chance of permanent invasion into bald areas subject to repeated fires.

Many mountaineers and woodsmen familiar with the region, as Mr. Andy Gregory, of the Little River Lumber Company, and Mr. Horace Kephart, of Bryson City, North Carolina, who are unusually close observers, think that fire is a very important if not universal factor in the initiation and maintenance of heath balds. Mr. Gregory recently told the writer that he has dug through one or two feet of peat in heath bald areas where there is no present indication of there having been a fire, but inevitably there is a charcoal layer at the bottom of the peat. The writer has had the same experience in many places. In some instances a black humus layer could be mistaken for charcoal, but even in a *Betula lenta* consociation at about 4,300 feet on the north side of Mt. LeConte I have found charred wood beneath a few inches of fibrous brown peat. Davis (5), working in the Black mountains of North Carolina, came to the conclusion that fire is an extremely important factor in this connection.

Despite the frequent importance of fire in eliminating trees from potential heath bald areas, it is not an exclusive factor, especially at higher altitudes, where landslides and windfalls are important contributing factors. Landslides have been conspicuous during the last two or three years in the vicinity of Dry Sluice Gap on the state line, on the Little Pigeon side of the Sugarland mountain near the Chimneys and on the upper Roaring Fork side of Mt. LeConte. It will be instructive to observe the return of trees or the establishment of balds in certain parts of these areas, as the case may be. Windfalls are numerous in the shallow-rooted spruce forests and especially where the fir, *Abies fraseri,* is dominant at higher elevations. When windfalls occur in locations suitable for the maintenance of heath balds, it is believed by the writer that trees do not come back.

In many situations, as along the divide between Myrtle Point, LeConte and the state line, and in certain places along the trail above Alum Cave, *Rhododendron catawbiense, R. punctatum,* etc., are so well-developed that they almost form a continuous cover under the spruce and fir. One can easily see that the elimination of trees by windfall or landslide would permit the closing in of the Rhododendrons and the establishment of heath balds. Soil and air conditions favoring the germination and establishment of conifer seedlings would be largely destroyed by the elimination of the tree cover, but the heath bald species could sprout and vegetate, rapidly forming a closed cover.

In brief summary of this section, it seems to the writer that the heath balds, from a successional point of view, are definitely postclimax, Weaver.(24). Heath bald species occur under the protection of the contiguous forest, and in more favorable locations (that is, more favorable for the heath bald species) they are so abundant that it seems clear that the elimination of the trees by catastrophic forces would result in establishment of balds, which would effectively, in many instances, prevent reinvasion by the forests.

SUMMARY

1. The ecology of a type of vegetation in the United States, apparently peculiar to the Southern Appalachian mountains and especially the Great Smoky mountains, is considered from a number of angles. These plant communities, here described for the first time, are referred to as "heath balds" because of their two most apparent aspects: (a) the dominant shrub flora is largely composed of species belonging to the heath family, Ericaceæ and (b) trees are absent from well-developed examples of this association.

2. The heath balds occur as restricted areas mainly on the windward sides of upper slopes and peaks with an altitudinal range of approximately 4,000 to 6,500 feet, being more frequent in the subalpine zone.

3. The heath balds have a fairly constant physiognomy throughout this altitudinal range, despite a considerable change in species content, and can be described briefly as broad-sclerophyll scrub with a considerable content of evergreen species. These facts are brought out by tables of the following data: (a) the relation of the flora of these island-like areas to the contiguous forests, (b) the change in species content with change in altitude, (c) an analysis of the flora according to Raunkiaer's

life-form classes and (d) leaf-size classes. Further statistical information on frequency and dominance is gained by use of quadrats on Brushy mountain.

4. The problem of the initiation, maintenance and distribution of the heath balds is considered on a basis of climatic, edaphic and catastrophic factors. It is concluded that the heath balds are postclimax, and consequently are derived from the contiguous forest associations as the result of the interaction of a number of factors. The combination and intensity of these factors may be various in the production of different heath balds by the local deterioration or destruction of the forest.

5. With cool and humid climatic conditions and evergreen vegetation, there is a decided development of edaphic conditions, as high acidity, peat formation and podsolization, which progressively favor heath bald species. In many places it is apparent that the elimination of the trees would permit the undershrubs to develop a closed cover, which they are apparently quite capable of maintaining, in most instances, against the encroachment of trees.

6. The biological equipment of the ericads is such as to favor them in competition with other plants under these rather extreme edaphic and climatic conditions, yet it must be understood that their occupancy of these areas is due more to their tolerance of the conditions, since their vitality is greater under the protection of trees.

The writer wishes to express gratitude to Professor George D. Fuller, of the University of Chicago, for suggesting the possibilities for ecological research in the Great Smoky mountains, and who has constantly guided these efforts during the past four years.

LITERATURE CITED

1. Braun-Blanquet et Pavillard. Vocabulaire de Sociologie Vegetale, 3d ed. Montpellier. 1928.
2. Cain, Stanley A. Soil Reaction and Plant Distribution in the Great Smoky Mountains, National Park, Tennessee. Bot. Gaz. (to appear in March, 1931).
3. Christopherson, E. Soil Reaction and Plant Distribution in the Sylene National Park, Norway. Trans. Conn. Acad. Arts and Sci. 27: 471-577. 1925.
4. Cooper, W. S. The Broad-Sclerophyll Vegetation of California. Carnegie Inst. Wash. Publ. 319.

5. DAVIS, JOHN H., JR. Vegetation of the Black Mountains of North Carolina: An Ecological Study. Jour. Elisha Mitchell Sci. Soc. 45: 291-318. 1930.
6. ENNIS, BUELAH. The Life Forms of Connecticut Plants and Their Significance in Relation to Climate. Conn. Geol. Nat. Hist. Surv. Bul. 43. 1929.
7. FISHER, R. T. Soil Changes and Silviculture on the Harvard Forest. Ecology 9: 6-11. 1928.
8. FROTHINGHAM, *et al.* A Forest Type Classification for the Southern Appalachian Mountains and the Adjacent Plateau and Coastal Region. Jour. Forestry 24: 673-684. 1926.
9. FULLER, G. D., and A. L. BAKKE. Raunkiaer's "Life Forms," "Leaf-size" Classes and Statistical Methods. Plant World 21: 25-37; 57-63. 1918.
10. JENNY, HANS, and J. BRAUN-BLANQUET. Vegetations-Entwicklung und Bodenbildung in der Alpinen Stufe der Zentralalpen. Denkschriften der Schweizerischen Naturforschended Gesellschaft 63: 183-342. 1926.
11. KENOYER, L. A. A Study of Raunkiaer's Law of Frequence. Ecology 8: 341-349. 1927.
12. LIVINGSTON, B. E. Atmometry and the Porous Cup Atmometer. Plant World 18: 21-30; 51-74; 95-111; 143-159. 1915.
13. —— and EDITH B. SHREVE. Improvements in the Method for Determining the Transpiring Power of Plant Surfaces by Hygrometric Paper. Plant World 19: 287-309. 1916.
14. LUTZ, H. L. The Vegetation of Heart's Content, A Virgin Forest in Northwestern Pennsylvania. Ecology 11: 1-29. 1930.
15. MAXIMOV, N. A. The Plant in Relation to Water (Trans. by R. H. Yapp). George Allen and Unwin, London. 1929.
16. ROMELL, L. G. Comments on Raunkiaer's and Similar Methods of Vegetation Analysis and the "Law of Frequency." Ecology 11: 589-596. 1930.
17. SCHIMPER, A. F. W. Pflanzen-Geographie auf Physiologischer Grundlage. Fischer, Jena. 1898.
18. SMITH, W. G. Raunkiaer's "Life Forms" and Statistical Methods. Jour. Ecol. 1: 16-26. 1913.
19. STICKEL, PAUL W. Physical Characteristics and Silvicultural Importance of Podsol Soil. Ecology 9: 176-187. 1928.
20. STOCKER, OTTO. Die Transpiration und Wasserokologie nordwest deutscher Heide und Moorpflanzen am Standort. Zeitschr. Bot. 15: 1-41. 1923. (Bot. Abs. 15, No. 435.)
21. —— Okologischpflanzengeographisque Unterschungen an Heide-, Moor- und Sals-pflanzen. Naturwissenschaften 12: 637-646. 1924. (Bot. Abs. 15, No. 435.)
22. THATCHER, K. M. The Effect of Peat on the Transpiration and Growth of Certain Plants. Jour. Ecol. 9: 39-60. 1922.
23. WARMING, E. Œcology of Plants (Trans. by Groom). Oxford Press. 1909.
24. WEAVER, J. W., and F. E. CLEMENTS. Plant Ecology. McGraw-Hill Book Co. 1929.