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ABSTRACT — A life-form study, using the Raunkiaer classification, was made of the spermatophytes of Minnesota. Three life-form spectra are presented: Minnesota (Ph 13.0%, Ch 3.0%, H 49.0%, Cr 22.0%, Th 13.0%); Clay County, a grassland area (Ph 12.3%, Ch 1.7%, H 53.7%, Cr 19.5%, Th 12.8%); and St. Louis and Lake counties, within the Boreal Coniferous Forest (Ph 14.9%, Ch 2.9%, H 47.2%, Cr 25.5%, Th 9.5%. (These data indicate that a hemicryptophytic climate prevails in Minnesota and are generally in harmony with Raunkiaer's assertions concerning the relation between life-form spectra and latitude.

During spring 1962, while on the staff of the University of Minnesota at Minneapolis, and during summers 1965 and 1966, while on the staff of the Lake Itasca biological station, I carried out field studies directed toward a life-form study of the Minnesota flora. Species not encountered in the field were studied from herbarium specimens. This paper presents a life-form analysis of the circa 1530 species of spermatophytes recorded as native to Minnesota (Moore and Tyron, 1946). Introduced species are not considered. Separate analyses are presented for the native floras of Clay County, a grassland county on the Minnesota–North Dakota border (Moore, 1958), and of St. Louis and Lake counties (Lakela, 1965), which are within the Boreal Coniferous Forest and border upon Lake Superior. The life–form classification used is that of Raunkiaer (1934; first published in 1908), which is based on the kind and degree of protection given the perennating buds during the unfavorable season. (A mimeographed list of the native spermatophytes of Minnesota, with life–form indicated for each, will be supplied upon request. These data are not included in the present paper because of space limitations.)

All too few life–form studies have been made on North American floras. Most pertinent to the present study are those for Kentucky (Gibson, 1963), Illinois (Hansen, 1952), Iowa (McDonald, 1937), Indiana (McDonald, 1937), western and Central Quebec (Scoggan, 1950), and the southern Mackenzie Great Plains (Thieret, 1963). Many additional life–form analyses are needed if the Raunkiaer system is to be critically evaluated for North America. The present paper is offered as a contribution toward this end. The only life-form studies previously done in Minnesota are those on a community — rather than a regional — basis by Buell and his associates (Buell and Wilbur, 1948; Stern and Buell, 1951; Miller and Buell, 1956).

Minnesota has an area of 84,068 square miles. Its elevation ranges from 602 ft. (Lake Superior) to 2230 ft. (Misquah Hills). With a continental humid climate, Minnesota has a mean annual temperature of 44°*F*. The record high temperature is 114°*F*.; the record low is −59°*F*. Winter cold increases from south to north as well as, to some extent, from east to west. Rainfall decreases from southeast to northwest, varying from about 32 in. to 20 in. The growing season is longest — about 160 days — in Minnesota's southeastern section; shortest — as little as 100 days — in the northern section.

Three of the climax vegetational formations of North America meet in Minnesota: the Boreal Coniferous Forest occupies the northeastern one-third of the state; the Grassland Formation occupies much of southern and western Minnesota; and the Deciduous Hardwood Forest Formation occupies a strip extending across the state from southeast to northwest between the Boreal Forest and the Grassland.

Raunkiaer's life–form system is independent of the usual classification of plants into species, genera, etc. It recognizes five principal classes that may be characterized as follows:

Class I. PHANEROPHYTES (Ph) bear their perennating buds 25 cm. or more above the ground and are almost all trees and shrubs. Because the buds are elevated and exposed to the full impact of the environment, and because the severity of conditions increases with height above the ground, phanerophytes are logically subdivided into height classes for life–form analysis. The height classes used in the present study are, mega–mesophanerophytes, over 8 m. tall; microphanerophytes, between 2 and 8 m. tall; and nanophanerophytes, between 25 cm. and 2 m. tall. Phanerophytes are predominant in humid–tropical floras and tend to decrease in proportion to other life–forms in regions with climates less favorable to such plant growth.

Class II. CHAMAEPHYTES (Ch) have their buds above the ground but lower than 25 cm. The buds are less exposed to the environment than those of phanerophytes. Generally, the percentage of chamaephytes in a flora tends to increase with increasing altitude or latitude or both. An especially high proportion of chamaephytes characterizes arctic and alpine floras.

Class III. HEMICRYPTOPHYTES (H) have their buds in the surface layer of the soil and are thus even better protected than chamaephytes. This class tends to

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be dominant in temperate floras and often constitutes half or more of the species in grasslands and deciduous forests; they are also common in tundra except under extreme conditions. Raunkiaer distinguished three principal subtypes, non–rosette or protohemicryptophytes, semirosette, and rosette. The first type is without basal rosette of leaves; the second has both basal and stem leaves; and the third has its leaves in a compact basal rosette.

Class IV. CRYPTOPHYTES (Cr) have their buds beneath the surface of the soil, in water, or in the substratum under water. The buds are manifestly much better protected than those of plants whose bud–bearing shoots are in or above the surface of the soil. Raunkiaer recognized three principal subdivisions, geophytes, helophytes, and hydrophytes. Geophytes are land plants, and their perennating structures are commonly bulbs, corms, rhizomes, stem–tubers, or root–tubers. Helophytes grow in soil saturated with water, or in the water itself, but their vegetative shoots are emergent. The hydrophytes include those aquatics that are free–floating and those that root in the substratum beneath the water but are not emergent. In the present study, hydrophytes and helophytes are combined into one class. Cryptophytes appear not to be the dominant life–form of any particular climate.

Class V. THEROPHYTES (Th) are annual plants that survive the unfavorable season in the form of seeds. They are particularly abundant in desert floras and in the weedy communities that develop after native vegetation has been disturbed.

The "life–form spectrum" of a particular flora shows the percentage–distribution of the five life–form classes in that flora. Such a spectrum can be used, in comparison with spectra of other floras, to reflect phytoclimatic differences between regions and to give an indication of the type of phytoclimate (i.e., whether phanerophytic, chamaephytic, hemicryptophytic, or therophytic) of the region concerned. Raunkiaer's Normal Spectrum was developed as the result of 1000 random samplings of the world flora. It may or may not represent accurately the flora of the world as a whole, but it does serve as a useful standard for comparison. Every regional spectrum will have one class (cryptophytes are not considered) whose percentage is significantly higher than that of the normal; this class can be taken as an indicator of the phytoclimate of the region.

Life–form data for Minnesota, Clay County, and St. Louis and Lake counties are presented in Table 1. Comparison between the Minnesota life–form spectra, selected other North American spectra, and the Normal Spectrum, is made in Table 2.

Until more life–form spectra are available for central North America, a student of life–forms must guard against drawing sweeping conclusions of the concepts of life–form and phytoclimate there. With regard to the Minnesota spectra, a brief discussion of certain of the data seems all that can be justified at present. This discussion may be introduced by the following quotation from Raunkiaer (1934:133).

> In the northern cold temperate and cold zones as we gradually go towards the north we find that the biological spectrum of the vegetation changes in a very definite manner. The Phanerophytes and the Therophytes decrease and finally disappear. The Cryptophytes, too, which are well represented throughout most of the region, disappear entirely from the hostile regions of the extreme north. The percentage of Hemicryptophytes keeps fairly constant, being approximately double the percentage found in the whole world. The Chamaephyte percentage on the other hand gradually increases towards the north; in the southern parts of the region it is a long way below the Normal Spectrum, but after reaching this figure it soon doubles it. Ultimately the Chamaephyte percentage becomes three times or more that of the Normal Spectrum. All these changes follow the same series everywhere, whichever meridian we follow.

It is evident that the phytoclimate of Minnesota is decidedly hemicryptophytic. The hemicryptophyte percentage is about double that of the Normal Spectrum, in line with Raunkiaer's assertion. The phanerophyte percentage is lower than that of states to the south. In addition, when compared to the phanerophytic flora of more southerly areas, that of Minnesota contains a *larger* proportion of species of *smaller* stature. (It is most curious that the Ph percentage in Quebec [16.6%; see Table 2] should be so high, nearly equal to that of Kentucky and, thus, significantly *higher* than that of Minnesota—instead of lower, as might be expected.) The chamaephyte percentage in the Minnesota flora is above the percentage of this class shown by floras of more southerly areas. It is, for example, double that of Kentucky. This relation is in harmony with Raunkiaer's postulate concerning the increase in percentage of chamaephytes with increase in latitude. Cryptophytes are well represented in Minnesota, the percentage being neither greatly above nor greatly below that of nearby areas. This same relation can be seen also in the therophyte percentage.

The Clay County and St. Louis and Lake counties are climatically (as well as physiographically and edaphically) different is evidenced by the fact that the two areas are occupied by different vegetational climax formations. That the areas are phytoclimatically different is revealed by their life–form spectra. The phanerophyte, chamaephyte, and cryptophyte percentages are higher for St. Louis and Lake counties; the hemicryptophyte and therophyte percentages are higher for Clay County. The difference in phanerophyte percentages is not so great as might be expected, considering the great difference in vegetation on the two areas. At least here, the difference between forested and grassland areas is not necessarily in the *percentage* of phanerophytic species in the floras but in the *dominance* of different life–forms in the vegetation. It is of interest to note that the higher percentage of chamaephytes in St. Louis and Lake counties is attributable primarily to the abundance of Ericaceae in

TABLE 1. Life-form data for Minnesota, Clay County, and St. Louis and Lake counties
(Figures represent percentages)

| | | Minnesota 1527 species | | Clay County 570 species | | St. Louis-Lake Counties 936 species | |
|---|---|---|---|---|---|---|---|
| I. | PHANEROPHYTES (Ph) | | | | | | |
| | Mega-mesophanerophytes | 4.1 | | 4.4 | | 4.8 | |
| | Microphanerophytes | 5.0 | | 5.1 | | 5.5 | |
| | Nanophanerophytes | 3.9 | | 2.8 | | 4.6 | |
| | Total Phanerophytes | | *13.0* | | *12.3* | | *14.9* |
| II. | CHAMAEPHYTES (Ch) | | *3.0* | | *1.7* | | *2.9* |
| III. | HEMICRYPTOPHYTES (H) | | | | | | |
| | Protohemicryptophytes | 14.6 | | 16.9 | | 12.3 | |
| | Semi-rosette Hemicryptophytes | 30.3 | | 33.9 | | 31.2 | |
| | Rosette Hemicryptophytes | 4.1 | | 2.9 | | 3.7 | |
| | Total Hemicryptophytes | | *49.0* | | *53.7* | | *47.2* |
| IV. | CRYTOPHYTES (Cr) | | | | | | |
| | Helo-hydrophytes | 7.9 | | 5.8 | | 10.6 | |
| | Geophytes | | | | | | |
| | Rhizome Geophytes | 8.9 | | 8.4 | | 9.8 | |
| | Stem-tuber Geophytes | 2.3 | | 2.5 | | 1.9 | |
| | Root-tuber Geophytes | 1.6 | | 0.9 | | 2.1 | |
| | Bulb Geophytes | 0.9 | | 1.6 | | 0.9 | |
| | Root-bud Geophytes | 0.2 | | 0.0 | | 0.2 | |
| | Root Parasites | 0.2 | | 0.3 | | 0.0 | |
| | Total Cryptophytes | | *22.0* | | *19.5* | | *25.5* |
| V. | THEROPHYTES (Th) | | *13.0* | | *12.8* | | *9.5* |

TABLE 2. Minnesota life-form spectra compared with spectra of selected other areas of North America and with the Normal Spectrum
(Figures represent percentages)

| | Ph | Ch | H | Cr | Th |
|---|---|---|---|---|---|
| Minnesota | 13.0 | 3.0 | 49.0 | 22.0 | 13.0 |
| Clay County | 12.3 | 1.7 | 53.7 | 19.5 | 12.8 |
| St. Louis—Lake Counties | 14.9 | 2.9 | 47.2 | 25.5 | 9.5 |
| Normal Spectrum | 46.0 | 9.0 | 26.0 | 6.0 | 13.0 |
| Indiana (McDonald, 1937) | 15.3 | 1.7 | 50.3 | 19.6 | 13.0 |
| Illinois (Hansen, 1952) | 15.5 | 1.6 | 50.2 | 19.8 | 12.9 |
| Iowa (McDonald, 1937) | 14.8 | 1.0 | 52.0 | 22.0 | 9.0 |
| Kentucky (Gibson, 1961) | 17.6 | 1.4 | 52.6 | 16.6 | 11.8 |
| Southern MacKenzie Great Plains (Thieret, 1963) | 11.9 | 7.7 | 55.7 | 18.7 | 5.1 |
| Western and Central Quebec (Scoggan, 1950) | 16.6 | 3.5 | 43.6 | 22.4 | 13.8 |

the area; there are no ericads at all in Clay County. The higher percentage of cryptophytes in St. Louis and Lake counties comes about primarily because these counties have a helo-hydrophyte percentage nearly twice that of Clay County, which, in turn, probably derives mainly from the greater availability of aquatic habitats in St. Louis and Lake counties. The higher percentage of hemicryptophytes and therophytes in the Clay County flora is, to me at least, not easily explainable.

The spectra for Clay County and St. Louis and Lake counties are probably more sensitive indicators of phytoclimate than is the spectrum for Minnesota as a whole, simply because the county spectra are based upon areas that are climatically and vegetationally more homogeneous than is the entire state. It is to be hoped that students of life–forms will prepare more spectra of such homogeneous areas rather than of larger diversified ones.

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# *The Effects of Solar Magnetic Activity on Electric Power Systems*

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ABSTRACT — Disturbances on large electric power transmission systems have been attributed to magnetic storms following solar flares. It can be shown that these magnetic disturbances are of the proper nature and magnitude to produce the documented effects on these electric systems. It is anticipated that these effects may become more serious with the greater and greater geographical spread of interconnected systems. More research and information on causal relationships is needed.

The facts that sun spots and other solar magnetic phenomena cause or at least influence the aurora borealis and have some sort of effect on long distance radio communication are widely known. Less generally known are the many other effects of such solar phenomena and the resultant fluctuations in the earth's magnetic field. Many of these "other effects" are very likely to become of increasing importance to electric utilities in their operation of large interconnected systems.

### Past Effects on Power Systems

It has been noted for some time that large anomalous flows of both real and reactive power can take place in electric transmission systems during geomagnetic activity — the so-called "magnetic storms." These "storms" follow solar flares that are themselves rather violent magnetic disturbances on the surface of the sun and only rather vaguely related to the sun-spots. One of the earlier documented cases of solar effects on power systems occurred during the great magnetic storm of March 24, 1940, when disturbances on numerous electric systems in the northeastern part of the country were noted and measured.[3] The Philadelphia Electric Company experienced voltage surges and reactive power swings of 20% as well as the tripping of two large power transformers. Several large power transformers also tripped on the Central Maine Power Company's system where voltage dips of up to 8% were also experienced. The Ontario Hydroelectric Power Commission had numerous cases of difficulty involving the tripping of large power banks due to differential operations.

This same storm also produced wide swings in charging current on 22 Kv lines of the Eastern Massachusetts Electric Company and large reactive power swings on the Northern States Power Company system in Minnesota and Wisconsin. Still further, the Consolidated Edison Company experienced voltage disturbances and dips of up to 10% and a large increase in reactive power requirements.

Additional systems in the northeast also experienced voltage dips and other difficulties. These systems included Boston Edison, Niagara Hudson, and Public Service Electric and Gas of New Jersey. The immediate causes of the voltage dips were direct currents flowing in the windings of many distribution and substation transformers that produced varying degrees of saturation of the cores.

This same magnetic storm produced rather drastic differences in potential between the ends of various telephone company long-line cables. One 27-mile cable went off scale at 100 volts, and recurring swings were observed for the next two hours; 340 volts was measured on one 240-mile line a week after the main storm. A recording

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