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**ON THE COVER** — The Bell Museum of Natural History at the University of Minnesota in Minneapolis is known widely to the general public as well as to faculty and students on campus as a depository of bird and animal exhibits and information. The museum is, however, a resource of botanical importance too. An article in the centerfold of this Journal issue pictures and identifies tree and plant material in the Bell Museum and discusses instructional uses of such material.

The Minnesota Academy of Science does not take a stand on issues which may be discussed in articles published in the Journal. Readers should bear in mind that views expressed in these articles are strictly those of the authors.
Lichen Studies on Allison Savanna

CLIFFORD WETMORE*

ABSTRACT — Soil and tree lichens were studied on the Helen Allison Savanna in Anoka County, Minnesota. Sample plots established in parts of the savanna have had fires at various time frequencies, and one section has had no recent fires. Fire has not eliminated any lichen species on the trees but has reduced their frequency in the lower trunk plots. Most soil species of lichens are eliminated by even infrequent fires. Fifty two species were found on trees and 13 species on the soil.

The Helen Allison Savanna Natural Area (owned by The Nature Conservancy) is located south of the Cedar Creek Natural History Area, east of Bethel in Anoka County, Minnesota. The land is gently rolling. Some low areas have marshes, and some of the dry knolls have sand blows. Scattered oaks and brush dominate most of the higher elevations. The Allison Savanna, a rectangular plot 550 meters in west-east direction and 410 meters in the north-south direction, has been divided into five north-south strips for experimental burning. Strips are called burn units in this report.

The easternmost burn unit (burn unit 1) has been burned most every year since 1962 (when burning began) and tends from the east fence to about 95 meters westward. The second burn unit is from 95 to 126 meters and has been burned about three out of four years. Burn unit three is from 126 to 160 meters and has been burned two out of every four years. Burn unit four extends from 160 to 180 meters and has been burned one year out of four. Burn unit five includes all of the area west of 180 meters, the eastern edge of the open field and probably has not been burned for at least 50 years.

This lichen survey is being done prior to scheduled initiation of burning in burn unit five to study the effects of burning on the lichens.

Methods of sampling for lichens

During the summer of 1980 work was begun by studying lichens present in the whole savanna except for the north open field. One hundred sample points were located at random in the forested area. At each sample point a 25 cm x 25 cm soil plots were established. The nearest tree within 15 meters and over 10 cm DBH was sampled.

If the trees, plots were located at the base, at 0.75 m, at 1.5 m up on the trunk. In each tree plot a line was scored around the sampled tree and the coverage of each species along the line was recorded as well as the compass directions of each segment of the line. Lichens were analyzed by computer according to burn unit, tree species, compass direction and band (top, mid, or base plot).

Table 1. Average number of lichen species in each burn unit in the top, mid, and base plots.

<table>
<thead>
<tr>
<th>Burn unit</th>
<th>Top</th>
<th>Mid</th>
<th>Base</th>
<th>Total</th>
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<tr>
<td>1</td>
<td>4.4</td>
<td>2.5</td>
<td>1.1</td>
<td>15</td>
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<td>2</td>
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<td>0.7</td>
<td>0.2</td>
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<td>3</td>
<td>4.1</td>
<td>3.3</td>
<td>1.8</td>
<td>13</td>
</tr>
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<td>4</td>
<td>4.3</td>
<td>3.7</td>
<td>2.3</td>
<td>12</td>
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<td>5</td>
<td>3.1</td>
<td>3.3</td>
<td>2.8</td>
<td>18</td>
</tr>
</tbody>
</table>

Table 2 lists all tree lichens by burn unit with the number of occurrences in the trunk plots and on the branches or outside of the plots. The columns labeled “T” indicate the number of trunk plots with that lichen species. The columns labeled “B” indicate the number of trees with that lichen present either on branches or outside of the trunk plots. Total trees and total species in each burn unit are at the bottom.

Table 3 lists the lichens found in the soil plots by burn unit and the number of plots in which each species present within each burn unit.

The lichen names used here follow Hale and Culberson (1975) and the identifications generally follow Hale (1979) for macrolichens and Harris (1977) for crustose lichens.

Analysis of lichen distributions

Fifty two species were found on the trees and 13 on the soil. When lichens in the tree plots were analyzed for trends with regard to compass direction, Physophrpla orbicularis was found more often on the southwest side of the tree, Phaeosonia detersa was found most often on the northwest, Parmelia borelliana and Parmelia flabella occurred most often on the northeast side. Those that showed significant absence on certain compass directions are: Arthonia caesia (SW), Parmelia borelliana (SW), Physciopsis adglutinata (NE), Physcia stellaris (NE), Physcia americana (SW).

There was no significant correlation between lichen species and tree diameter. Some species were found significantly more often on certain species of trees: Arthonia caesia and Physcia stellaris on Quercus ellipsoidalis E.J. Hill, Physcia aipolia on Fraxinus pennsylvanica March.

When comparing the tree plots on trunks in different burn units there is a strong reduction in the number of

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trees with lichens at the base and a reduction in numbers of species in the base and middle plots in the burned areas, but the total numbers of lichen species on tree trunks remains about the same in all burn units (Table 1).

It is obvious that even infrequent burning (as in BU 4) greatly reduces lichens at the base and frequent burning (BU 1 and BU 2) also reduces the lichens up to the mid plot at 0.75m from the ground. There also seems to be a significant reduction in the number of species on the lower branches in burned areas, as shown in Table 2.

Most of the soil plots did not have lichens, but burning significantly reduces the number of species found and the numbers of plots with lichens. In the unburned area (BU 5) the lichens probably cannot compete with the vascular plants. Any fire destroys most species, and the lichens do not have enough time to recover before the subsequent fire.

The number of lichen species on tree trunks above about 1 meter is not significantly reduced by burning, regardless of frequency. The numbers of lichen species on tree trunks below 1 meter and on tree branches below 2 meters is significantly reduced by burning, even infrequent burning. Any fires decrease the frequency of lichens at the bases, but infrequent fires have less effect in the 0.75m plots. Most soil lichens are largely eliminated by any fires and only sterile Cladonia squamules are present in burned areas.

ACKNOWLEDGEMENTS

Funds for this study were provided by The Nature Conservancy, Minnesota Chapter. This assistance is gratefully acknowledged.

REFERENCES


TABLE 2. Allison Savanna Lichens - Trees

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<td>B</td>
<td>T</td>
<td>B</td>
<td>T</td>
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<tr>
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X = not in plot; (X) = outside study area; 4 = number of times recorded

TABLE 3. Allison Savanna Lichens - Soil

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<th>BU 5</th>
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<td>16</td>
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X = not in plot; (X) = outside study area; 4 = number of times recorded

The number of lichen species on tree trunks above about 1 meter is not significantly reduced by burning, regardless of frequency. The numbers of lichen species on tree trunks below 1 meter and on tree branches below 2 meters is significantly reduced by burning, even infrequent burning. Any fires decrease the frequency of lichens at the bases, but infrequent fires have less effect in the 0.75m plots. Most soil lichens are largely eliminated by any fires and only sterile Cladonia squamules are present in burned areas.

Acknowledgements

Funds for this study were provided by The Nature Conservancy, Minnesota Chapter. This assistance is gratefully acknowledged.
Direct Impact of Forest Harvesting in Northeastern Minnesota

PHILIP L. FRIEST *

ABSTRACT — Direct impact of harvesting operations is examined as one segment in a survey of interrelationships between elements of the primary forest products industry in northeastern Minnesota, an area known popularly as the Arrowhead Region. This study follows classifications used in collection of data for 1977 from seven Minnesota counties. Information is based largely on responses from companies involved. An Input-Output model was employed in the study for assessing expenditures by loggers for wage payments, purchase of timber stumpage, vehicles and equipment operation, financial services, and employee benefits (FICA, etc.). Comparisons of relative proportions of expenditures by loggers within the study region and income generated from outside the region are utilized in measuring the economic impact of direct harvesting.

This paper reports on part of a large study of the primary forest products industry in seven counties of northeastern Minnesota. The industry was defined to include the logging (harvesting) of the forests; sawmills producing lumber products; a miscellaneous group consisting of Christmas trees, firewood, posts, poles, etc.; and the pulp, paper and board mills and plants. Aitkin, Carlton, Cook, Itasca, Koochiching, Lake and St. Louis were the seven counties in northeastern Minnesota comprising the geographic area for the study.

The investigation was directed toward discovery of the types, quantities (in terms of dollar expenditure), and the geographic origins of the intermediate inputs (i.e., purchases from other firms) that are required by the primary forest products firms operating in the seven counties. Obviously, the more vertically integrated the firm, the less inputs it buys from outside, and the more its value added contribution becomes a part of its total sales dollar. In the same way, the more vertically integrated the industry, the less inputs it buys from firms outside the industry, and the more the industry value added contribution becomes a part of the total sales dollar of the industry.

The organizing model for information required for the study was the Input-Output model, modified to identify the intermediate inputs specifically required by firms in the primary forest products industry. Information for the year 1977 was collected directly from the firms. Data for each of the four parts of the industry were collected and analyzed independently and then aggregated to obtain totals representative of the industry as a whole. The study focused solely on direct contributions of the forest products industry and did not attempt to measure its indirect impact. Nor did it address the contribution and interaction of the other business sectors which make up the total economic community of northeastern Minnesota.

Representatives from various firms were involved in the planning of the research project and reviewed the questionnaire for terminology and applicability to the industry. Mail questionnaires were addressed personally to the owner, operator, manager or corporate official (as appropriate) of firms studied.

The data generated are based upon the information reported directly by cooperating firms. It was not feasible to seek responses from each firm in the industry, nor was it possible to use statistical sampling techniques. Therefore, no attempt is made to provide a measure of potential error that might be present in the data. The expenditures reported for the individual intermediate inputs required by the industry are conservative values and appear to be supported as reasonable estimates by secondary data sources employed to provide a check on their accuracy.

The Harvester Requirement Side

Lists of loggers operating in the seven counties were obtained from the Minnesota DNR and other sources. These lists included the commercial loggers and did not include part-time operators who engage in logging to supplement other sources of income. One-third of the names were selected on a random basis. Remaining names were reviewed, and additional ones were selected so that a total of 44 were included in the mailing of questionnaires.

Loggers have traditionally been hard working individuals who seek the independence inherent in harvesting the forests and in the rural lifestyle of northern Minnesota. Therefore, it was not surprising that even after three separate mailings over a period of almost 5 months the response rate was low. Fortunately, the respondents included a broad range — single family operators, partnerships, operations with only small numbers and amounts of part-time employment, and operators with very sizable payroll. Other sources are available to estimate the total size of the harvesting sector of the industry but it was critical in this case to obtain information from a variety of firms to gain a reasonably complete picture of the nature of the economic inputs required by the harvesting sector. Even though the response rate was lower than desired, the variety of responding firms does provide very valuable data concerning the nature, and size, and sources...

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of the direct inputs required by this industrial sector in northeastern Minnesota.

Saw Logs and Pulpwood Dominant

Sales of saw logs and pulpwood represented approximately 97 percent of total 1977 sales reported by the logging firms responding to the questionnaire. The total sales of the harvesting sector were, therefore, determined on the basis of the production of saw logs and pulpwood in the seven counties during 1977. Production data was obtained from regular publications of the U.S. Forest Service.

Information on pulpwood production from roundwood by county and species was obtained from Pulpwood Production in the North Central Region, by County, 1977, by Blyth and Smith. These reported quantities were priced using Minnesota Forest Products Price Review for 1977 by the Minnesota Department of Natural Resources. The resulting values were used as the sales value of pulpwood from the harvesting sector of the industry in the seven counties.

Saw log production data for Minnesota during 1977 were not available for the study. It, therefore, was necessary to adjust the 1975 data from Lake States Primary Forest Industry and Timber Use, 1975, by Blyth, Whipple, Boeter and Whilem to an estimated 1977 production. The trends in saw log production of the Upper and Northern Lower Peninsulas of Michigan have been found to most closely approximate the trends in saw log production in northeastern Minnesota. Therefore, the trends from 1975 to 1977 in those areas of Michigan were used to adjust the 1975 production of saw logs in the seven counties to arrive at a 1977 production estimate. This estimated production by county and species also was priced using the Minnesota DNR pricing review. The resulting values were used as the sales value of saw logs harvested.

The sum of pulpwood value and saw log production became the basis upon which sales for the harvesting sector were estimated. Total sales are important to place the proper perspective on harvesting as a part of the total primary forest products industry. To use unweighted sectoral data in aggregating the totals for the industry would have placed undue influence upon the reported sales exchanges, and the sales expenditure distributions of the smaller sectors of the industry.

Loggers reported only one percent of sales to be outside the state of Minnesota, and 98 percent of their sales were made within the seven county study region. For the industry as a whole, almost 69 percent of the sales were made outside Minnesota and only 10 percent within the seven county area. Table A reports the geographic sales patterns for each of the four sectors of the industry and for the industry as a whole.

The loggers also reported that 99.9 percent of their sales were to business firms, the balance to households. No sales were reported to governmental units or for export. For the industry as a whole, 98 percent of sales were to business firms, almost one percent to households, less than one percent for export and one-tenth of one percent to governmental units. Table B reports sales by sector and purchaser.

Area Sales Follow National Market Pattern

It is quite apparent from the nature of the output, saw logs and pulpwood, and the reported sales to business firms that almost the entire forest harvest in the seven counties of northeastern Minnesota flows to other sectors of the primary forest products industry. Its income is highly dependent upon the national market demand for lumber and paper products, since almost 60 percent of the sawmill sector and 75 percent of the pulp, paper and board sector sales are made in the national market.

Sales of products produced by the harvesting sector generate the dollars to obtain the various inputs for carrying on the logging activities. As noted, the primary objective of the research was to measure the type, quantity and geographic sources of these inputs, particularly the intermediate inputs (those purchased from other firms). The data reported by respondents engaged in logging in the seven counties of northeastern Minnesota form the basis for identifying each of the different products and services, their geographic source and the relative significance of each.

The first analysis is in terms of the relationship of each category of expense to the total expenditures reported by the firms for 1977. A second analysis attempts to follow the traditional Input-Output model, using the total sales dollars generated by harvesting as the base, and thus includes a measure of the value added for the sector.
The logging firms reported that approximately 91 percent of their total 1977 expenditures were made to entities within the seven county study area and 3 percent outside the state of Minnesota. For the industry as a whole, almost 29 percent of expenditures were outside Minnesota and approximately 33 percent within the seven counties of Northeastern Minnesota.

Table one lists the percentage of 1977 expenditures of the harvesting sector for each category of expense. Approximately 52 percent of the total was for employment related costs, with 43 percent directly for wages. The cost of equipment and its operation and maintenance required more than 26 percent of the total expenditures in 1977. Almost 15 percent was for stumpage, the price paid to take trees from the land. All stumpage costs have been included as an expenditure of the harvesting sector even though some harvesting may be done on forest land owned by a paper plant or from land on which the stumpage rights have been purchased by a paper company with the pulpwood being delivered directly to the plant. This approach places the total stumpage cost in one sector and is consistent with the pricing of pulpwood and saw logs used to determine the sales value for products of the harvesting sector. These three categories of expense account for 93 percent of the total, with the balance going for all the other types of goods and services such as interest, taxes, accounting services, or chain saws.

Approximately 9 percent of the total expenditures of loggers were made outside the seven counties. Of these expenditures, 39 percent were to the state and federal governments for taxes, licenses and social security and unemployment payroll taxes. Less than 1 percent was for miscellaneous purchases from other business firms. Employee insurance and retirement plans took 6 percent and 54 percent was for workmen’s compensation insurance.

The harvesting sector is very closely tied to the economy of the seven county Arrowhead region of Minnesota. Almost its entire output of product is consumed within the area, and the necessary support firms are found within the seven counties to supply goods and services required in logging. Only the state and federal governments and the premiums for insurance draw sales dollars generated by the products of the harvesting sector out of the seven counties of northeastern Minnesota.

**Input-Output Analysis and the Direct Requirements Table**

Professors Wayne Jesswein and Richard Lichty, Department of Economics at University of Minnesota-Duluth, have completed a study (1974) for the seven counties of northeastern Minnesota plus adjacent Douglas County in Wisconsin. Their report included a Direct Requirements Table using a 35-sector model (reduced from the U.S. 87 sector 1967 model I-O table) and included Lumber and Furniture (sector 9) and Pulp and Paper (sector 10) as two of the sectors. Table 2 of this study reports the results of the Jesswein-Lichty research for these two sectors and adds a third and fourth column for the industry totals and the harvester sector using data from the present research.

**TABLE 1 - PERCENTAGE OF 1977 EXPENDITURES BY EXPENSE CLASSIFICATION HARVESTER SECTOR FOREST PRODUCTS INDUSTRY NORTHEASTERN MINNESOTA**

A direct requirements table is constructed so that the sum of the column represents one dollar of sales by the sector identified in the column. Each item in the column represents the portion of one dollar which the sector uses to buy goods and services from the industry sector identified on the line.

The study suggests that the harvesting sector assigns ten cents of each dollar of sales to the stumpage price of harvested trees. Almost five cents is used to buy petroleum products and another eight cents goes for purchase of equipment. This may seem high for what has been traditionally a very labor intensive activity, but it results from modern-day new, large equipment in the forests. Interest cost on borrowed capital and the purchase and operation of logging and transport equipment required fifteen cents of the 1977 sales dollar.

The goods and services purchased from other firms required a total of thirty-two cents in 1977 (the sub-total in the column) and twenty-nine cents went to wages. Value added is reported to be thirty-eight cents of the sales dollar. As expected, this is relatively high because
The sectors reported in the four columns in Table 2 are related but not identical. Therefore, intersectoral relationships would not be expected to be the same. In addition, the Lumber and Furniture industry and the Pulp and Paper columns from the Jesswein and Lichty study are based upon data from the U.S. Department of Commerce national input/output table for the year 1963. The Minnesota Two Region Model, developed by Wilbur Maki, and incorporated in the Jesswein-Lichty study, was utilized in constructing the regional data for these industry sectors. Two columns were constructed from primary data for 1977 supplied directly by the firms which completed questionnaires for this study. Difficulty was encountered in identifying a few of the reported expenses with the specific industry sector from which the purchase was made. Until further research has been completed, the data reported may be most significant for identification of industries from which the harvesting sector draws support and for pointing out that firms representing these industries have located in the Arrowhead region of Minnesota.

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Alternative Hypotheses on Ecological Effects of Meningeal Parasite (Parelaphostrongylus tenuis)

GLEN F. COLE*

ABSTRACT — *P. tenuis* is a ubiquitous parasite of white-tailed deer (*Odocoileus virginianus*) that can cause mortality in woodland caribou (*Rangifer tarandus*) and moose (*Alces alces*). A hypothesis that *P. tenuis* prevents overlapping distributions of these species in southern boreal regions was inconsistent with distribution records. A revised hypothesis that *P. tenuis* does not prevent overlapping distributions if deer exist at natural densities was consistent with these records but did not state the parasite’s ecological effects. A hypothesis that *P. tenuis* allows deer to outcompete woodland caribou or moose on portions of natural environments or in man-modified environments where deer densities are relatively high appeared to be consistent with published accounts of mortality from the parasite and other reviewed literature. Thus, statements that *P. tenuis* either does or does not prevent or restrict overlapping distributions of woodland caribou or moose with white-tailed deer need to be further qualified.

*Parelaphostrongylus tenuis* is a non-host specific parasite of white-tailed deer (Anderson 1972, Lankester et al. 1976). Infection is by accidental ingestion of terrestrial gastropods which are an intermediate host for the parasite’s larval stages. This parasite does not appear to cause significant mortality in white-tailed deer. It is known to cause mortality in experimentally infected woodland caribou and moose calves (Anderson and Strieve 1968, Anderson 1964) and in a woodland caribou placed on an island populated with white-tailed deer (Behrend and Witter 1968), in woodland caribou placed in a fenced enclosure with high densities of deer (Trainer 1973), in moose in the wild (Anderson 1965) and in European reindeer (*R. t. tarandus*) placed on an island with deer (Anderson 1974).

From the mortality of experimentally infected woodland caribou and reindeer introduced onto an island with white-tailed deer, Anderson (1972) predicted that it will not be possible to reintroduce caribou into areas where deer have a high prevalence of *P. tenuis*. Trainer (1973) believed that his unsuccessful introductions of caribou into an enclosure with high deer densities supported this prediction. Both authors also suggested the possibility that the parasite was a factor in the declines of woodland caribou on the southern portions of their range. Others (Smith 1940, Harper 1965, Bergerud 1974, Benson and Dodds 1977) have attributed declines to excessive hunting in combination with habitat changes or increases in predators or deer with *P. tenuis*. Evidence that reintroductions of caribou can fail in habitats where moose still occur, but deer with *P. tenuis* became abundant, is presented by Dauphine (1975).

Moose - Deer relationships examined

Trainer (1973) reports that introductions of moose into an enclosure with high densities of deer with *P. tenuis* also failed. Others (Karns 1967, Telfer 1967, Behrend and Witter 1968, Kelsall and Prescott 1971, and Gilbert 1974) have attributed decreases or increases in free-ranging moose to corresponding increases or decreases in deer densities. However, several of these authors and Kearney and Gilbert (1976) also present evidence that differences in habitat use by time and/or area allow moose and deer with *P. tenuis* to be sympatric species.

Woodland caribou, moose, white-tailed deer and elk (*Cervus elaphus*) were all present before and during the early stages of settlement and logging in the Voyageurs National Park area (Cole 1979). Extribations of caribou and elk and declines of moose to remnant numbers by the early 1920’s were associated with hunting which provisioned early settlements, logging camps, and homesteads. However, over a 1907 to 1939 period when the area’s forests were first logged (Rakestraw et al. 1979) deer increased from relatively low densities (possibly less than 2/km2) to high densities of 8 or more/km2 as reported by Erickson et al. (1961). Declines back to low densities occurred despite the absence of other cervid competitors (moose remain a non-viable remnant) and were mainly associated with maturing forests.

Another possible interpretation, from the literature reviewed thus far is that the mortality of caribou or moose from *P. tenuis* results from density-influenced interspecific competition. Such competition characteristically prevents competitors of a species from appropriating the portions of an environment (or niche) where the species has a competitive advantage (Miller 1967). Competition usually maintains the densities and distributions of competing species in some dynamic equilibrium, but can contribute to complete or partial replacements if changes due to climate or man favor one species over another. The validity of this and alternative interpretations are explored in the following section.

Approaches to testing alternative hypotheses

Hypotheses about complex ecological relationships can be easily deduced but are difficult to test in the laboratory or field. An approach described by Poore (1962) involves testing a stated hypothesis by systematically seeking information to show it is false. Any inconsistent information requires that a hypothesis be rejected and restated for consistency with all information. Repeated rejections and restatements ultimately result in a refined hypothesis that is consistent with a broad base of reference information and less likely to be false.

Some interpretations about *P. tenuis*, in the form of testable hypotheses, follow. These assume the parasite is ubiquitous in white-tailed deer and transmissions are mainly

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functions of deer and other cervid densities and distributions. They only apply to large areas of mainland, southern boreal forest vegetation, and not to islands that lack sufficient space or habitat diversity to accommodate species with overlapping requirements. Deer densities are assumed to be usually less than 2 per km² under natural conditions, and to increase three-fold or more in man-modified environments.

1. *P. tenuis* prevents overlapping distributions of woodland caribou and/or moose with white-tailed deer.
2. *P. tenuis* does not prevent overlapping distributions of woodland caribou and/or moose with white-tailed deer, if deer occur at natural densities.
3. *P. tenuis* allows white-tailed deer to outcompete woodland caribou and/or moose on the portions of natural boreal forest environments where deer densities are highest (e.g., winter or spring concentration areas).

The first hypothesis paraphrases interpretations from some of the early literature on *P. tenuis*. It must now be rejected because it is inconsistent with additional evidence that white-tailed deer either had or still have overlapping distributions with woodland caribou and moose in some southern boreal forest regions. Hall and Kelson (1959) show the original distributions of all three species overlapped along the southern boundary of boreal forest communities (Whitaker 1970). Reports by Curry-Lindahl and Harroy (1972), Freddy and Erickson (1975) and Stardom (1975) show all three still coexist in several Canadian and one adjoining U.S. area, but it is not certain that *P. tenuis* is present in all of these locations (Anderson 1972). However, records of commercial sales of meat of caribou, moose and white-tailed deer in a 1894-1901 gold-rush settlement (Treuer 1979) and detailed accounts of hunting all three species in a 1889-1901 diary by E.L. Brown (Unpub. transcription, Minnesota Historical Society) tend to establish that all were present in northern Minnesota before the natural vegetation was changed by logging.

The second hypothesis that *P. tenuis* does not prevent overlapping distributions if deer occur at natural densities is a rephrasing of the first so it is consistent with species distribution records. It is also consistent with the reviewed papers that show differences in species densities or distributions, by time or area, allow coexistence of deer with *P. tenuis* and moose. Similar relationships can be predicted for deer and caribou. This prediction could be tested by reintroducing caribou into southern boreal environments where deer with *P. tenuis* occur at natural densities.

The third hypothesis (*P. tenuis* allows deer to outcompete caribou and/or moose on portions of areas where deer densities are highest) predicts the actual ecological effects of this parasite in a relatively stable southern boreal environment. Environmental changes from natural or human influences could result in more or less competition and corresponding changes in species distributions and densities. This hypothesis seems consistent with species distribution records, the literature which shows *P. tenuis* can cause mortality in caribou or moose, and the accumulated evidence that such mortality can be a function of both densities and distributions of deer. It is also consistent with an abundant literature which shows that species with partly overlapping requirements must compete or interfere with each other to coexist. This literature is reviewed by Allee et al. (1949) and Miller (1967).

Both tentative conclusions may be correct.

As is often the case in biology, conclusions which appear to be conflicting are both correct, but for different situations. In man-modified environments that support higher-than-natural deer densities, *P. tenuis* can prevent or restrict caribou and moose from having overlapping distributions with deer. In natural southern boreal environments that support low deer densities, *P. tenuis* does not prevent overlapping distributions and may actually allow deer to coexist with caribou or moose. A recently discovered ubiquitous parasite (*Elaphostrongylus cervi*) in woodland caribou (Lankester et al. 1976) may similarly prevent moose, and possibly other cervids, from excluding caribou from their particular niche in southern boreal environments. Such relationships, where a non-specific parasite provides its usual host with a competitive advantage, are probably common in mixed species systems and an important contribution to species diversity. Further tests of the hypotheses developed here are encouraged.

ACKNOWLEDGEMENTS

M. Lankester and T.C. Dauphine and P.D. Kerns reviewed an early draft of the paper and made helpful suggestions. Any errors of interpretation in the final paper are mine.

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Companies and Individuals Aided St. Cloud Science Fair

The extent of financial support and voluntary help for the Minnesota Academy of Science by companies and individuals is illustrated by the backers of the Central Minnesota Regional Science Fair held at St. Cloud University in 1980.

David Grether, who served as finance chairman, and Leonard Soroka, coordinator of the event, both faculty members at St. Cloud State, expressed special thanks to the following for both support of the regional fair and the impact of their contributions in helping to send winners to the higher levels of competition with projects and research reports.


Dumont Signs, R.F. Rafferty, M.D., Niskern Agency, Inc., Robert Koenig, M.D., Roger A. Slanga, M.D., H.M. Broker, M.D. Dinnendorf Paint and Wallpaper, Michael H. Donohue, Attorney, De Zurik Corporation, Royal Tire Co. (Don Dean)

Faculty members of St. Cloud State University: John Coulter, Hugh Barker, Mohammed Bahauddin, Wayland Ezell, Michael Garrity, Alexander MacWilliams, John Carpenter, Donald Peterson, Leonard Soroka, Science Fair Coordinator; David F. Grether, Science Fair Finance Chairman.

Youth Dimension Expanding in Academy’s Program Goals

Although Spring and Fall membership meetings are the most visible activities of the Minnesota Academy of Science, two functions directed to young and future scientists have achieved increasing attention in recent years.

An annual Junior Science, Engineering, and Humanities Symposium gives selected high school and junior high students opportunities to present and share research papers and projects with their youthful contemporaries over a wide area. Starting with local programs, outstanding students can move through statewide, regional and national levels and finally compete for major scholarship awards. This program is co-sponsored by leading industries as well; and it serves North and South Dakota students as well as those from Minnesota schools.

The State Science Fair and Research Paper Program climaxes the selection process for choosing Minnesota’s participants in the Junior Symposium described above. Also an annual event, the State Science Fair is presented in alternate years at a Twin Cities location (The Minneapolis Lemonig hotel in recent years) or at another Minnesota city, usually a college town.
Herbert Brown Challenges Scientists to Search Boldly for Good of Mankind

Almost 200 members and friends of the Minnesota Academy of Science attended the Academy’s own “Nobel Prize” dinner and lecture by Dr. Herbert C. Brown, a 1979 Nobel Laureate in Chemistry.

In 1980 Dr. Brown received the Priestley Medal, also one of the world’s most prestigious chemistry awards.

The Nobel occasion, at Macalester College in St. Paul was a pioneering fund raiser for the Minnesota Academy and brought together several former students and associates of Professor Brown to hear a recapitulation of his Nobel lecture and review of the research and development of organoboranes. The 1979 Nobel Prize in Chemistry was shared by Dr. Brown and Dr. Georg Wittig of Germany for related but independent work.

As a special climax to the dinner, the host academy of science presented Dr. Brown a signed wildlife painting by Dr. Walter J. Breckenridge. Dr. Breckenridge, retired director of the Bell Museum of Natural History at the University of Minnesota, also is a former president of the Minnesota Academy of Science and is nationally recognized as a wildlife artist. Prints of the work were given to dinner attendees. Jack Mauritz, a more recent past president of the Minnesota Academy of Science, originated and directed the event, and Ms. Roslyn Fletcher, a former student of Dr. Brown and now a member of the faculty of the Minneapolis Community College, introduced the speaker.

In recounting his 43 years of organic synthesis investigations, Dr. Brown likened the research, which in his case had begun in 1936 with thesis studies and culminated in organoborane development and the Nobel Prize 40 years later, to the ancient poetic expression, “great oaks from little acorns grow.” At the outset, he recalled, diborane, B2H6, was manufactured in just two laboratories (one at Chicago, the other in Germany) and was so rare a substance that its production was only in gram quantities. A year’s output by an eight-man team under the methods then in use would have produced one kilogram of diborane.

Alternatives and experiments were traced in the Nobel lecture through the efforts of Brown and others whom he described as “exceptionally capable co-workers” until, he said, it became “clear that the organoboranes are among the most versatile chemical intermediates available to the chemist.”

Even though the Academy dinner was basically a social-type of gathering, Dr. Brown did display his essential academic and instructor nature by turning to a blackboard that had been installed behind the podium and chalking several equations to illustrate chemical structures. Then, in the concluding part of his lecture, he looked to future challenges growing from the historic advances and said he hoped thus to “transmit a message to younger colleagues.”

“When I received my Ph.D. degree (1938),” he said, “I felt that organic chemistry was a relatively mature science, with essentially all of the important reactions and structures known. There appeared to be little new to be done except the working out of reaction mechanisms and the improvement of reaction products.” Now, he recognizes, new reagents are available and numerous new structures are known as a result of discoveries during the years since his early interest. He alluded again to the acorn-to-oak analogy but emphasized that he had in mind a much earlier start, when the acorn was no more than a mere grain of pollen. Finally, he said, there had been great and rapid progress as the acorn became an oak and the oak became a forest to the point where we “are beginning to see the outlines of a continent.”

Nobel Laureate Brown told his Minnesota Academy of Science audience that he believes it will be up to a future generation of chemists to “settle that continent and to utilize it for the good of mankind.” And he expressed the confidence that there are similar continents awaiting discovery by enthusiastic, optimistic explorers and inspired young chemists, all searching for such new continents.
Fig. 1 - Number key to plants in Maple-Basswood Forest photograph

1. *Asarum canadense*  
   Wild Ginger
2. *Tilia americana*  
   Basswood
3. *Ipsipryum biternatum*  
   False Rue Anemone
4. *Mertensia virginica*  
   Virginia Cowslip, Bluebells, Lungwort
5. *Arisema triphyllum*  
   Jack-in-the-Pulpit, Indian Turnip
6. *Aplectrum hyemale*  
   Putty Root, Adam and Eve
7. *Phlox divaricata*  
   Wild Blue Phlox, Wood Phlox
8. *Hydrophyllum virginianum*  
   Virginia Waterleaf
9. *Viola pubescens*  
   Common Yellow Violet
10. *Allium tricoccum*  
    Wild Onion, Wild Garlic, Wild Leek
11. *Cornus alternifolia*  
    Alternate-leaved or Pagoda Dogwood
12. *Trillium cernuum*  
    Nodding Trillium
13. *Trillium grandiflorum*  
    Large-flowered Trillium
14. *Dicentra cucullaria*  
    Dutchman's Breeches
15. *Sanguinaria canadensis*  
    Bloodroot
16. *Maianthemum canadense*  
    False Lily of the Valley

The Bell Natural History Museum

ABSTRACT – Much of the regular academic year does not lend itself to observation of plants in their natural habitat outdoors. The museum exhibits can serve as study aids in the off season, although they should not be utilized as substitutes for field work. This study systematized some materials available for class use. Museum files, display legends, and original observations were used.

From the Bell Museum of Natural History, 112 exhibits were listed and coded for location; 384

The James Ford Bell Museum of Natural History at the University of Minnesota contains a wealth of material for students interested in plants, especially those native to Minnesota, their identification and their environmental associations. Of the 112 exhibits included in this study, only two are exclusively titled by the plants which they feature (Maple-Basswood Forest and Spruce-Fir-Pine Forest); one, Wild Lupine and Lark Sparrow, bears a title shared with a bird.

While virtually all the exhibits are titled by the names of the animals, they nevertheless contain fine examples of plant life as a part of the natural habitat for those animals.

Exhibits certainly should not be used as a substitute for field work or in place of a detailed laboratory study of plants, but they may indeed serve as a valuable learning aid during winter months, for convenient reviews, and for appreciating the plants associated together in various habitats.

Exhibits usable in “off-season”

Museum visits have been particularly helpful to my students who register for a course in Taxonomy taught during the January Interim or for a course in Spring Flora. Field recognition of plants is impossible for the first of these courses; it may be unlikely for the second, depending on the lateness of spring and an academic calendar in which

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**BELL MUSEUM OF NATURAL HISTORY**

**Museum, An Aid to Teaching Botany**

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17. *Claytonia virginica*
   Spring Beauty

18. *Erythronium sibirum*
   White Dog-tooth Violet
   White Trout Lily, Adder's Tongue

19. *Lysichiton americanus*
   Large-flowered Bellwort

20. *Erythronium propullans*
   Dwarf or Minnesota Dog-tooth Violet

21. *Trillium nivale*
   Snow Trillium

22. *Acer saccharum*
   Hard, Rock, Sugar Maple

23. *Hepatica acutiloba*
   Sharp-lobed Hepatica, Liverleaf

24. *Viola sororia*
   Common Blue or Sister Violet,
   Downy Blue Violet

25. *Collybia velutipes*
   Velvet-stemmed Collybia

26. *Urnula craterium*
   Black Urn Fungus

27. *Sarcoscypha coccinea*
   Scarlet Cup Fungus

28. *Ostrya virginiana*
   Ironwood, Hop Hornbeam

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The listing includes locally-used common names to facilitate reference to the material by a person who may have only casual interest in plant identification. More serious students would, of course, wish to use addition references for more extensive taxonomic description.

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*Photo, courtesy of Bell Museum of Natural History*
ACKNOWLEDGEMENTS

The author is indebted to many individuals for assistance in this project. Special thanks are due to Don Luce of the museum for his cooperation. The contribution of Dr. Edward Cushing of the University of Minnesota is acknowledged for his listing of some of the plants in 1977, as are the helpful suggestions of Dr. G. B. Ownbey. Finally, thanks are due to those unidentified individuals who through their work left valuable information on the display legends or in the museum files, and to Steve Carpenter for preparing the drawings.

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Composition of Goldenrod (Solidago: Compositae) Populations by Species in the Upper Midwest

WILLIAM E. MILLER*

ABSTRACT — In each of 100 abandoned agricultural fields grown over with goldenrod, stems were diagnosed and counted in 20 occupied 0.4-m plots selected by hoop tossing. Preliminary results differed little between hoop tossing and random plot selection, and between 0.9 and 0.4 m² plot sizes. In rank order of stem abundance the taxa were Solidago altissima L., S. canadensis L., complex S. gigantea Ait., S. graminifolia (L.) Salis., S. nemoralis Ait., S. ulmifolia muhl. others. An average of 2.2 taxa were recorded per field, and three or more taxa in at least one plot in 34 percent of fields. Where S. altissima-S. canadensis complex stems were resolved to species, S. altissima was approximately three times more abundant than S. canadensis.

Goldenrods comprise a diverse assemblage of Solidago species which reproduce by seed and rootstocks. They occur in various upper midwest plant communities (Curtis 1959) but are most abundant in intermediate stages of secondary successions. Some species can attain dominance 5 to 15 years following abandonment of agricultural land and retain it for 15 to more than 25 years (Bazzaz 1968, Drew 1942, Quarterman 1957), depending on factors such as soil porosity and last crop (Beckwith 1954).

Despite advancing knowledge of goldenrod growth requirements (Werner and Platt 1976) and numerous studies of secondary succession, there is no clear picture of the relative abundance of different taxa in upper midwest goldenrod populations, nor how frequently their stands are mixed. The present study examines these questions by extensive sampling in abandoned agricultural fields, one of the commonest goldenrod habitats. The study developed from an interest in goldenrods as hosts of monophagous insects (Miller 1959, 1963, 1976) and as positive and negative influences on various human activities. Some goldenrods are valued in apiculture as late-season sources of pollen and nectar (Gertel 1939) and some are potential sources of rubber (Polhamus 1933). However, some are allegedly allelopathic (Brown and Roti 1973) and several upper midwest species introduced into Europe reduce moisture and other resources available to tree seedlings, prompting forestry interest in their control (capek 1971).

Hoop-tossing method preferred

One hundred study fields were chosen using the following criteria: (a) sub-continuous vegetation cover occupying a potential sample area between 0.2 and 0.5 ha, (b) half or more of vascular stems consisting of goldenrod, and (c) no woody vegetation taller than goldenrod in the sample area. Study fields were taken as encountered during motoring and none were contiguous. Goldenrod was at or near its population peak in such fields.

All goldenrod stems taller than 6 cm were counted in each of 20 occupied plots per sample area. In one-fourth of the sample areas, stems of other vascular plants also were counted to monitor subjective determination of relative goldenrod abundance.

Tossing a circular light-weight tubular hoop was the preferred method for selecting plots in sample areas because it facilitates rapid sampling of many fields in a wide area. The hoop was tossed again if it did not land around at least one goldenrod stem; no more than two additional tosses were necessary in any field.

Before placing reliance on hoop tossing, however, results were compared with strictly random selection of occupied plots. Square sample areas 0.2 to 0.4 ha were established in continuous stands with sides parallel to cardinal directions each providing more than 3,000 potential non-overlapping 0.4 m² plots. After a cardinal orientation was chosen randomly, 20 plots were selected by drawing location coordinates from a random number table, and 20 were selected by hoop tossing.

Two plot sizes, 0.4 and 0.9 m², both within the range commonly used in such sampling, were likewise compared.
Table 1. Relative abundance of Solidago taxa in 0.4 m² occupied plots selected by hoop tossing (a) and random process (r) in 0.2 to 0.4 ha sample areas. Data presented as a/r.

| No. | Solidago Field stems in 20 plots | Percentage Solidago: | Percentage | Percentage |
|-----|---------------------------------|-----------------------|------------|
|     | alt-can                          | gig                   | nem        | gram       | spec       |
| 1   | 267/290                          | 51/47                 | 1/5        | <1/1       | 0/0        | 0/0        |
| 2   | 311/327                          | 4/4                   | 2/0        | 0/0        | 2/2        | 3/1        |
| 3   | 531/532                          | 14/10                 | 0/0        | <1/1       | 0/0        | 0/0        |

1 Species abbreviated: alt-altissima, can-canadensis, gig-gigantea, nem-nemoralis, gram-graminifolia, rig-rigida, spec-speciosa

Table 2. Relative abundance of Solidago taxa in nested 0.4 and 0.9 m² occupied plots selected by hoop tossing. Data presented as small plot/large plot.

<table>
<thead>
<tr>
<th>No.</th>
<th>Solidago Field Stems in 20 plots</th>
<th>Percentage Solidago:</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>alt-can</td>
<td>gig</td>
<td>nem</td>
</tr>
<tr>
<td>1</td>
<td>276/620</td>
<td>2/3</td>
<td>2/2</td>
</tr>
<tr>
<td>2</td>
<td>214/456</td>
<td>32/27</td>
<td>2/2</td>
</tr>
<tr>
<td>3</td>
<td>291/639</td>
<td>15/16</td>
<td>1/1</td>
</tr>
<tr>
<td>4</td>
<td>284/641</td>
<td>37/36</td>
<td>1/2</td>
</tr>
<tr>
<td>5</td>
<td>215/463</td>
<td>0/0</td>
<td>8/8</td>
</tr>
</tbody>
</table>

1 Species abbreviated as in Table 1.

before one size was adopted. This comparison was done by using a hoop of 0.4 m² area centered inside a 0.9 m² hoop.

Fields were sampled between August 14 and October 19—the goldenrod flowering period—to aid species identification. Rapid diagnosis was possible except for two pairs whose members are very similar: Solidago altissima L.—S. canadensis L. and S. juncea Ait.—S. missouriensis Nutt. Each was recorded as a complex. In certain fields where multiple visits and intensive study were feasible, S. altissima and S. canadensis were separated for counting based on differences in flowering period, involucre length, and leaf and stem characters. Available involucre length criteria (Fernald 1950) did not seem to accurately separate these species; the criteria were therefore adjusted to local frequency distributions which ranged from 2.1 to 4.5 mm, and to fresh material as well which was found to be 9 percent longer before herbarium shrinkage (30 n). Karyotype examination following Beaudry and Chabot (1957) of one typical specimen of each species supported diagnoses. Voucher specimens from this study are in the Michigan State University Herbarium, East Lansing.

Comparison of results

The sampled fields were located in parts of Minnesota, Iowa, Wisconsin, Illinois, Michigan, Indiana, and Ohio (Fig. 1).

Results obtained by hoop tossing and random plot selection in three Minnesota fields are compared in Table 1. In two of these fields more species were recorded by hoop tossing, but this is probably fortuitous because the additional species were uncommon. The greatest difference in the comparison was five points; from this it was concluded that hoop-tossing results approximated random-plot results.

Results obtained with the two hoop sizes in five Minnesota fields are compared in Table 2. The same species appeared in both plot sizes. The greatest difference in the comparison was five points; from this it was concluded that
hardly more information was gained in the 0.9 m² plot size than in the 0.4 m², and the latter was adopted for the study.

Eight Solidago taxa were recorded in the 100 study fields (Table 3). In relative stem abundance, rank order was S. altissima-S. canadensis complex > S. gigantea > S. graminifolia > S. nemoralis > S. ulmifolia > others. Relative abundance of S. altissima-S. canadensis complex and S. gigantea, the two most common taxa, remained constant through much of the five-fold range in goldenrod density index (Table 4). In the 25 fields where all vascular stems were counted, goldenrod comprised from 53 to 99 percent of stems, averaging 82 percent.

In seven Michigan fields where S. altissima and S. canadensis were largely separated, the first species was approximately three times more abundant than the second (Table 5). If these results are extended to the whole study, S. canadensis approaches S. gigantea in relative stem abundance. In Wisconsin fields, resolution of S. altissima-S. canadensis complex into species was more difficult and the attempt was abandoned.

More than one taxon was recorded in 80 percent of study fields. This number depends on true proportion of stems of each taxon in the sample area, and on intensity of sampling. Twenty tosses of the 0.4 m hoop produced an average of 2.2 taxa per sample area. At least one plot containing three or more taxa appeared in 34 percent of sample areas, and the maximum in one plot, four areas appeared in eight percent of the sampled plots.

In conclusion, eight constituent taxa were recorded in upper midwest old field Solidago populations. Solidago altissima-S. canadensis complex is the most abundant taxon, and S. altissima probably the most prevalent species. Relative abundance of the two most common taxa was not influenced by overall goldenrod stem density. Mixed stands are common as judged by maximum numbers of taxa per 0.4 m² plot. Finally, results apply to stem density, not to individual plant or clone density; cloning propensity could differ among species.

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Table 3. Relative abundance of Solidago taxa in sample areas of 100 upper midwest fields.

<table>
<thead>
<tr>
<th>Solidago</th>
<th>Percentage fields where recorded</th>
<th>Percentage in fields where recorded</th>
<th>stems in all fields</th>
</tr>
</thead>
<tbody>
<tr>
<td>altissima-L.-canadensis-L. complex</td>
<td>98</td>
<td>75</td>
<td>74</td>
</tr>
<tr>
<td>gigantea</td>
<td>56</td>
<td>28</td>
<td>16</td>
</tr>
<tr>
<td>graminifolia (L.) Salisb.</td>
<td>39</td>
<td>12</td>
<td>4.7</td>
</tr>
<tr>
<td>nemoralis Ait.</td>
<td>22</td>
<td>16</td>
<td>3.2</td>
</tr>
<tr>
<td>ulmifolia Muhl.</td>
<td>11</td>
<td>13</td>
<td>1.4</td>
</tr>
<tr>
<td>rigida L.</td>
<td>7</td>
<td>2</td>
<td>0.1</td>
</tr>
<tr>
<td>ursina Ait. missouriensis Nutt. complex</td>
<td>4</td>
<td>3</td>
<td>0.1</td>
</tr>
<tr>
<td>speciosa Nutt.</td>
<td>2</td>
<td>35</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Table 4. Relative abundance of Solidago altissima-S. canadensis complex and S. gigantea with respect to overall Solidago density.

<table>
<thead>
<tr>
<th>Index No.</th>
<th>Solidago stems/m²</th>
<th>No. of Fields</th>
<th>Mean percentage Solidago</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 - 20</td>
<td>26</td>
<td>71</td>
<td>30</td>
</tr>
<tr>
<td>21 - 30</td>
<td>28</td>
<td>76</td>
<td>26</td>
</tr>
<tr>
<td>31 - 40</td>
<td>27</td>
<td>72</td>
<td>28</td>
</tr>
<tr>
<td>41 - 50</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total 100</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Not absolute density because occupied plots were used.

Table 5. Relative abundance of S. altissima and S. canadensis in 20 fields.

<table>
<thead>
<tr>
<th>Field No.</th>
<th>No. occupied plots</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>186</td>
</tr>
<tr>
<td>2</td>
<td>254</td>
</tr>
<tr>
<td>3</td>
<td>160</td>
</tr>
<tr>
<td>4</td>
<td>246</td>
</tr>
<tr>
<td>5</td>
<td>236</td>
</tr>
<tr>
<td>6</td>
<td>136</td>
</tr>
<tr>
<td>7</td>
<td>202</td>
</tr>
<tr>
<td>Mean</td>
<td>198.2</td>
</tr>
</tbody>
</table>


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Nutritional Preferences Exhibited By Plants In Ad Libitum Feed Systems

L. A. ERREDE*

ABSTRACT—Ad libitum feeding plant systems fitted with two reservoirs were used to monitor daily aqueous uptake by plants from paired reservoirs. When the reservoirs contained aqueous solutions of the same chemical composition, a plant accepted nourishment from alternate sources without bias; but when the reservoirs contained different aqueous solutions, i.e., either tap water or standard nutrient solution, a sharp bias was exhibited, depending on the plant's need for mineral nutrient, which changed with time. Eventually a "stable-end-state" was attained, favoring water over the standard nutrient solution in the ratio of 3 to 1. When the plant was pruned severely, however, preference oscillated sharply from one source to the other for six months while new growth developed to reestablish the "stable-end-state". If a toxic pollutant was added to the favored reservoir, the plants preference switched sharply to the other source until the toxicant was eliminated from the polluted reservoir, thus ensuring the plants survival.

It was reported (Errede and Ronning 1980) that the permeability of certain microporous membranes, placed in intimate contact with a water reservoir on one side and the root network of a plant on the other, is controlled by that plant in accordance with its chronobiological needs for aqueous nourishment. Daily water uptake by the plant in such ad libitum feeding systems oscillates in a pattern that exhibits a weekly cycle, superimposed on a lunar cycle, which in turn is superimposed on a seasonal cycle. The seasonal cycle is characteristic of the plant species, but the weekly cycle and perhaps the lunar cycle appear to be universal for all plants in a given general area, i.e. the oscillations are well synchronized as if all the plants in isolated locations were responding to a common stimulis, probably the pattern of alternating light and darkness.

When such systems are fitted with two or more reservoirs, (insets of Figs. 1 through 5) it is possible to challenge that plant with a nutritional option by refilling the reservoirs daily with aqueous solutions of different chemical compositions. Typical results for such an experiment are shown in Fig. 1, which plots in the lower portion the daily uptake, V₁ in cc/day, by a ficus japonica plant from each of its two 285 cc capacity reservoirs, No. 1 and No. 2, as a function of time, and in the upper portion the corresponding percent of the total uptake, V₁ + V₂, supplied by reservoir No. 2, i.e., P₂ = 100 V₂/(V₁ + V₂). The data recorded over the first three weeks shows the characteristic manner in which water permeability of the microporous membrane decreases as a function of continued water flow (Errede and Martinucci 1980). Plant control over water permeability is established when root contact is made with the membrane, usually within a few weeks. Thereafter, V₁ oscillates as shown after day 25.

Fertilizer solution introduced after 80 days

In this experiment both reservoirs No. 1 and No. 2 were refilled daily for 80 days with tap water. During this period

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pointed above and below a line given by $P_2 = 25$ percent, which corresponds to a "stable-end-state" bias of about 3-to-1 in favor of water over the arbitrary standard nutrient solution.

The characteristic drift from a no-bias initial state ($P_2 = P_0$) to the "stable-end-state" bias of ca. 3-to-1 in favor of water is shown more clearly in Fig. 2. This is a plot of the averaged percent preference for reservoir No. 2 i.e. $P_2$, exhibited by the set of 23 coleus systems whose daily uptakes of aqueous nourishment from reservoirs No. 2 and No. 2 were monitored independently by volunteers (Listed in the acknowledgment). The large amplitudes in the oscillating $P_2$ patterns for the individual systems (Fig. 1; top portion), were essentially eliminated in the averaged $P_2$ patterns (Fig. 2) showing clearly that the oscillating pattern for percent preference by one plant is not in synchrony with that of another plant of the same species. Essentially the same results were obtained when the data for $VT = V_1 + V_2$ for sets of 12 Dieffenbachia, 9 ficus elastica and 7 Schefflera, which also were monitored independently by the volunteer group, were treated in like fashion. This means that $P_2$ for a given self feeding system changes independently in accordance with its individual needs despite that $VT = V_1 + V_2$ of this system oscillates rhythmically in synchronization with all other plant systems of the same species as shown for example in Fig. 3, which plots the average total daily uptake, $VT$, for the same set of 23 coleus systems recorded in Fig. 2.

Reservoirs assignment reversed as check

To demonstrate that the observed "stable-end-state" at $P_2 = 25$ percent is not attributable to the fact that the smaller reservoir (No. 2) was refilled daily with standard nutrient solution and the larger reservoir (No. 1) was refilled with water, the refill assignments for the paired reservoirs were reversed on day 530 for a sub-set of 4 of the set of 23 coleus systems. This reversal caused $P_2$ for each number of the test set to rise from $22 \pm 2$ percent on day 530 to $74 \pm 3$ percent on day 700 as indicated by the dashed line beginning at 16 April 1979 in Fig. 2; whereas $P_2$ for the remaining 19 systems in the control set increased only from $22 \pm 2$ percent to about $24 \pm 2$ percent during the same interval. Thus the 3-to-1 bias in favor of water is established by the plant regardless of the refill assignment.

This observed "stable-end-state" bias has no real theoretical significance except in a qualitative sense. It is a fortuitous result associated with the arbitrary choice of one gram of soluble mineral nutrient per gallon of water, which was chosen for convenience. It was shown, albeit with only one plant system, that this bias ratio was about 5 to 1 when the concentration of the nutrient solution was doubled.

It was observed that the initial response exhibited by a self-feeding plant challenged with a nutritional option depends on the history of the system. In those examples in which the system had been conditioned by refilling the paired reservoirs with water, the initial response to the option was to swing sharply in favor of reservoir No. 2, which was refilled daily with standard fertilizer solution; the percent of total aqueous uptake supplied by this reservoir increased from $P_2 = P_0$ to $P_2 > 60$ percent, depending on the time allowed for depletion of original soil nutrients before the system was supplied daily with standard nutrient solution. This initial response was followed by oscillations of greater than 15 percentage points above and below a line that descended gradually to the same "stable-end-state" line given approximately by $P_2 = 25$ percent.

In those examples in which the system had been conditioned by refilling the paired reservoirs with standard fertilizer solution, the initial response to the option was to swing sharply in favor of reservoir No. 1, which was refilled daily with water; the percent of total aqueous uptake supplied by reservoir No. 2, which contained nutrient solution; decreased from $P_2 = P_0$ to $P_2 < 15$ percent, depending on the time allowed for accumulation of excess nutrients before water was supplied daily. This initial response was followed by oscillations of less than 2 percentage points above and below a line that ascended gradually to the same "stable-end-state" line given by $P_2 = 25$ percent, which was established in the above examples from the opposite direction.

Response to chemical and physical perturbations

After the "stable-end-state" is established, the percent preference for reservoir No. 2 oscillates within a narrow range, i.e. ca. 5 percentage points above and below a line that corresponds approximately to a 3-to-1 bias in favor of the water reservoir. Oscillation within this relatively narrow range continues so long as the system remains undisturbed by chemical or physical perturbations. Whenever a toxic pollutant is added to one of the paired reservoirs, however, the percent preference for the other reservoir increases sharply. This cause and effect relationship is illustrated in Fig. 4 which plots the average percent preference, $P_2$, for the test set of n-systems relative to that of the control set (23-n systems) during the same time interval. In the first test (28 April 1978 to 1 August 1978) reservoir No. 1 of three coleus systems were refilled daily from 28 April 1978 to 26 June 1978, with 0.1 percent methylamine.

Figure 2 - Chronological average percent preference for reservoir No. 2 exhibited by a set of 23 coleus in ad libitum feeding systems fitted with two reservoirs as shown in the inset.
hydrochloride solution instead of water. This chemical perturbation caused the percent preference, \( P_2 \), for reservoir No. 2, which contained standard nutrient solution, to increase in each of the test systems from \( P_2 = 34 \pm 1 \) percent to \( P_2 = 89 \pm 2 \) percent as indicated by the averaged data for the test set (solid line), whereas the averaged \( P_2 \) for the control set (dashed line) remained relatively constant during the same time interval. Preference for reservoir No. 2 began to decrease after 14 September 1978 when the toxic pollutant was eliminated from reservoir No. 1, and normal selectivity of \( P_2 = ca. 30 \) percent was reestablished by 1 August 1978.

In the second test (26 August 1978 to 1 December 1978), reservoirs No. 1 of two coleus systems were refilled daily from 26 August 1978 to 14 September 1978 with water saturated with \( \text{H}_2\text{S} \). This chemical perturbation caused \( P_2 \) to increase from 29 percent and 30 percent to 88 percent and 90 percent respectively, as indicated by the average data for the test set (solid line Fig. 4), whereas the averaged \( P_2 \) for the control set (dashed line Fig. 4) remained relatively constant. Preference for reservoir No. 2 began to decrease after 14 September 1978, when the toxic pollutant was eliminated from reservoir No. 2, and normal selectivity of \( P_2 = ca. 25 \) percent was reestablished by 1 December 1978.

In the third test (8 January 1979 to 30 March 1979), reservoirs No. 1 of three coleus systems were refilled daily from 8 January 1979 to 6 March 1979 with 0.1 percent aqueous acetic acid solution. This caused \( P_2 \) to increase from \( P_2 = 25 \pm 1 \) percent to \( P_2 = 55 \pm 3 \) percent as indicated by the average data for the test set (solid line Fig. 4), whereas the averaged \( P_2 \) for the control set (dashed line Fig. 4) remained relatively constant during the period. Again preference for reservoir No. 2 began to decrease on 6 March 1979, when the reservoir No. 1 was again refilled daily with water, and normal selectivity of \( P_2 = ca. 24 \) percent was reestablished by 30 March 1979.

Physical damage to the plant also causes marked perturbations in the preference pattern. If, for example, much foliage is removed by pruning, the system exhibits unusually large oscillations in \( P_2 \) above and below the no-bias line at \( P_0 \) until such time that the plant can recover from the physical damage by growing new foliage. Usually this recovery to the “stable-end-state” occurs within six months.

**Potential applications in a wide range**

The results described in this and earlier publications (Errede and Ronning 1980) show that these ad libitum feeding arrangements can be used as a means for studying plant-water relationships. Because of their ease of assembly, and relative simplicity, they are particularly useful in experiments that involve multiple replications that must be monitored over long periods. This can be done periodically or even continuously if the systems are interfaced with a computer, eliminating the drudgery of processing enormous quantities of recorded data. Systems fitted with multiple reservoirs, for example, could be used in the study of ion preferences, i.e. Na\(^+\) vs. K\(^+\) or \( \text{SO}_4^{2-} \) vs. \( \text{HPO}_4^{2-} \), or in the study of tolerance and receptivity of physiologically active organic compounds, such as growth regulators or systemic insecticides.

The ad libitum feeding capability can of course be adapted to horticultural applications, especially when water availability is limited, as in the southwestern part of the United States, Israel, Egypt and Iran. It also has obvious utility in the care of houseplants to preclude over-or-under watering. Because of the plant’s ability to control flow from alternate sources with different chemical compositions, systems with two reservoirs can also be used to preclude over or under fertilization. In this regard, the present

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**Figure 3** - Chronological pattern of averaged daily total aqueous uptake exhibited by a set of 23 coleus in *ad libitum* feeding systems assembled as shown in the inset.
and for selecting appropriate bioresponsive microporous water varriers have been described previously by the authors.

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(*Deceased)

REFERENCES


Area File of Associations
at Hill Reference Library

A file of professional and business associations of the St. Paul-Minneapolis area has been made available at the James J. Hill Reference Library in St. Paul, and the library invites additional inputs of information.

The Hill Library, at Fourth and Market Streets in downtown St. Paul, is open to the general public for direct resource use and also maintains a telephone reference service in the fields of business and economics that form its central focus.

The association file includes listings of local area groups and also local contacts for national associations. Listings of officers and membership directories of some are included.
Scaled Chrysophycae From Lake Itasca Region

I. Mallomonas

DANIEL E. WUJEC,* MICHAEL M. WEIS,** ROBERT A. ANDERSEN***

ABSTRACT—By means of electron microscopy, phytoplankton samples from the Lake Itasca region were examined for the silica-scaled chrysophycean genus Mallomonas. Seventeen taxa were observed: 15 are new for Minnesota, of these 15, seven are also new reports for the continental United States.

The freshwater algal flora of the Lake Itasca region has been documented in a series of articles by Meyer and Brook (1968, 1969a, 1969b). Included in these floristic lists are a number of silica-scaled chrysophytes, all based on light microscopy. No electron micrographs of the scale or bristle structure of Chrysophycean material from Minnesota were known to have been published to the time of this publication; and as knowledge of the ultrastructure of the scale and bristles is essential, and in most cases necessary for correct determination, it was considered of value to publish the present electron micrographs.

This presentation is intended to be in a series of papers detailing the silica-scaled chrysophytes of Minnesota. This first part pertains to the genus Mallomonas Perty. It contains more described species than any other genus in the Synuraceae. Mallomonas species are unicellular, free-living, photosynthetic freshwater algae. Cells are covered with a siliceous layer of scales with or without spines and moveable bristles.

Preparation of Samples for Electron Microscopy

Forty-nine samples were collected in the region of Lake Itasca, Minnesota, with a plankton net during the summers of 1977 and 1980. Preparation of samples for electron microscopy used the technique for diatom cleaning in order to remove organic matter (Patrick and Reimer, 1966). Material was heated in nitric acid and a small amount of potassium dichromate. The samples were then brought to neutral pH through a series of decantings with distilled water. From the concentrated sample, one to two drops were air-dried on Formvar-coated grids. Electron micrographs were taken on a Philips EM 300 or a Siemens Elmiskop transmission electron microscope.

Those species marked with an asterix are new records for Minnesota. Those marked with a double asterix are new to the continental United States. Figures are numbered individually on the full-page plate.

The Species Observed

**Mallomonas aerolata** Nygaard (Fig. 1)

A rarely observed species, it has been reported only from Denmark (Asmund, 1959) and Japan (Takahashi, 1975). We observed it in both the North and South Deming Ponds.

*Mallomonas caudata* Iwanoff em. Kreiger (Fig. 2).

*M. caudata* is a very widely distributed species. We observed it from East and West Twin Lakes.

**Mallomonas cratis** Harris and Bradley (Fig. 3)

This species was collected from the Wild Rice River (Hwy. 200). It has been previously observed from the U.S., Europe and Japan.

**Mallomonas cratis** var. Asmundiae Wujek and Van der Veer (Fig. 4)

Originally described from Holland, it has since been observed from Arkansas (Andersen, 1978) and Texas (Marquis, 1977). Representative scales were observed from Darling Pond.

**Mallomonas crassisquama** (Asmund) Fott (Fig. 5)

This taxon was first described by Asmund (1959) from material collected in Denmark. Asmund’s report pointed out that this species is distributed widely in the northern latitudes. Our collections bear this out, as it was the most commonly encountered species in our collections. Our specimens were found in Long Lake, North Deming Pond, Josephine Lake, West Twin Lake and a pond at mile marker 53 on Hwy. 113 in Clearwater and the edge of Hubbard counties in Minnesota.

**Mallomonas eao** Takahashi (Fig. 6)

We found a few scales of this species in our sample from Darling Pond. In addition to Europe and Asia, this taxon has been reported from North America (Alaska) by Asmund and Takahashi (1969).

**Mallomonas grata** Takahashi (Fig. 7)

An infrequently observed species world wide, we observed scales belonging to *M. grata* from Darling Pond.

**Mallomonas glabra** (Bourrely) Asmund (Fig. 10)

This species, originally described as a variety of *M. reginae*, has also been described as *M. transsylvanica* Peterfi and Momeu (1976). This taxon is one of the few readily observed species world wide, we observed scales belonging to *M. grata* from Darling Pond.
Mallomonas species. Fig. 1. M. aerolata, x6,800. Fig. 2. M. caudata, x6,800. Fig. 3. M. cratis, x10,200. Fig. 4. M. cratis var. asmundiae, x6,800. Fig. 5. M. crassiquama, x6,800. Fig. 6. M. eoa, x10,200. Fig. 7. M. grata, x6,800. Fig. 8. M. heterospina, x6,800. Fig. 9. M. mangofera, x10,000. Fig. 10. M. glabra, x10,000. Fig. 11. M. insignis, x6,800. Fig. 12. M. multiuncia, a. scale, x6,800 b. helmet bristle x3,200. Fig. 13. M. papillosa, x10,200. Fig. 14. M. pillula, x10,000. Fig. 15. M. pumilo, x10,200. Fig. 16. M. tonsurata, a. scale, x6,800 b. tip of bristle, x6,800. Fig. 17. M. conifera, x6,800.

Itasca Algae

*Mallomonas heterospina* Lund (Fig. 8)

A widely distributed *Mallomonas* species, our micrographs closely resemble previous observations. It was found recognized using light microscopy (LM). It occurred in Darling Pond. It previously was observed in the U.S. from North Carolina by Bourrelly (1957) using LM.

*Mallomonas insignis* Penard (Fig. 11)

The scales are of the same ultrastructure as previously reported by various authors. First illustrated from the U.S., but not identified by Wee et al. (1976) from Iowa.

in the Beaver Pond on Hwy. 4, Wild Rice River and the North Deming Pond, fitting well its occurrence in other highly eutrophic waters in other parts of the world.
it has since also been reported from Arkansas (Andersen, 1978). Scales of this species were found in the West Twin Lake and Darling Pond samples.

**Mallomonas mangofera** Harris and Bradley (Fig. 9)

It was found in Darling Pond. Previously it has been described only from England (Harris and Bradley, 1960), Scotland (Bradley, 1966) and Japan (Takahashi, 1975).

**Mallomonas multiformis** Asmund (Fig. 12)

The South Deming Pond collection contained a few scales and bristles of this species. This organism has a distinctive helmet bristle. The body scale has a characteristic ribbing on the dome area.

*Mallomonas papillosa* var. *papillosa* Harris and Bradley (Fig. 13)

A very small species, it can be recognized only by means of EM. First described from England (Harris and Bradley, 1957), it has since been reported from a number of countries, including the United States (Wujek and Hamilton, 1972; Andersen, 1978). Samples with this taxon were from the North Deming Pond, Deming Lake and Darling Pond.

**Mallomonas pillula** Harris (Fig. 14)

First observed in England (Harris, 1967), it has since been observed in Iceland (Bradley, 1964) and Alaska (Asmund and Takahashi, 1969). We observed it only once from Darling Pond.

*Mallomonas pumilo* var. *pumilo* Harris and Bradley (Fig. 15)

It was found in the plankton of Darling Pond.

*Mallomonas tonsurata* Telling em. Kreger (Fig. 16)

This species has been found in several eutrophic ponds and lakes in Europe, Asia and the United States. Our specimens were collected in comparable habitats: East Twin Lake and the Wild Rice River.

**Mallomonas coronifera** Matv. (Fig. 17)

Our collections from the North Deming and Darling ponds represent the first observations of this species from North America.

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