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Volume 67, 1979

Editor
FOREST STEARNS

TRANSACTIONS OF THE WISCONSIN ACADEMY

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WISCONSIN ACADEMY OF SCIENCES, ARTS AND LETTERS

The Wisconsin Academy of Sciences, Arts and Letters was chartered by the State Legislature on March 16, 1870 as an incorporated society serving the people of the State of Wisconsin by encouraging investigation and dissemination of knowledge in the sciences, arts and letters.

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The TRANSACTIONS of the Wisconsin Academy of Sciences, Arts and Letters is an annual publication devoted to original papers, preference being given to the works of Academy members. Sound manuscripts dealing with features of the State of Wisconsin and its people are especially welcome; papers on more general topics are occasionally published. Subject matter experts review each manuscript submitted.

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ROBERT A. McCABE

57th President 1979
WISCONSIN ACADEMY OF
SCIENCES, ARTS AND LETTERS

STATE OF THE ACADEMY

ROBERT A. MCCABE

Presidential Address

April 1979

Seven score and 19 years ago our forefathers brought forth for this State a new association . . . our Academy. It was dedicated to the proposition that there was a need to encourage investigation and disseminate views of the various departments of Science, Literature and the Arts. Now we are engaged in a grave financial crisis testing whether this academy or any academy so conceived and so dedicated can long endure without direct public support—in whose interest it directs its efforts and its programs.

* * *

I acknowledge paraphrasing our most illustrious U. S. president for that introduction. It would have been a great relief for me at the outset to recite for you our accomplishments over the past year, compliment those who have performed well, tell a light story or perhaps a few jokes and to have thus amused you without being very enlightening.

What I am about to relate to you is not meant to be nor should it be construed as criticism or complaint, neither is it a heralding of doom. But . . . our Academy is in serious financial difficulty. The full impact of this difficulty has not yet been felt in our programing or by the membership. Inflation and a virtually static source of income, coupled with litigation of the McCoy trust suspending income from that source are parties to the problem. In short we have had to borrow from the capital of our endowment fund to maintain our program of service. This has been an anathema to the Academy Council. Belt tightening has already begun and more will doubtless follow.

Although some money saving adjustments have been made, the major effort has been voluntarily undertaken by our Executive Director. He has launched a fund raising campaign with the backing of the Academy Council. Three quarters of the Director's time has been and will continue to be devoted to this effort. Results thus far have been encouraging but not overwhelming.

Laudable as this effort is both as a personal undertaking and as an Academy program for self maintenance, the following facts must be understood and acceptable to the membership.

1. That the funds raised and to be raised are not to increase the endowment, or repay funds taken from the endowment; instead, they are to be used to meet current expenses.
2. That until we adjust our life style or obtain outside financial aid, this fund raising effort will be an annual affair. How long we can expect donors to repeat on an annual basis is yet to be determined.
3. If the Executive Director does indeed spend most of his time fund raising, who then minds the shop? We have a dedicated and competent office staff, but it would be unrealistic and unfair to saddle them with responsibilities not in their job descriptions.
4. Can we afford, financially and administratively, to use our Executive Director nine months of each year as a fund raiser? My personal reply is that we cannot!
5. Lastly, unless the Academy is the sole winner in the McCoy court case our financial woes will become chronic.

If this untenable situation distresses you, as it does me, then we must delineate and examine our options. When any company or organization is losing money, its first remedial action is to cut back on goods and services. Our goods are our publications and our first line responsibility. The Academy *Transactions* by common accord must not be diminished or diluted, but since most scientific journals today require a page charge for published articles, this possibility is being exploited but is also under careful study. *The Academy Review* is our most popular publication and is perhaps the major offering the Academy makes to the lay membership. Recent discussions on the *Review* have called for expansion, not retrenchment. Our newsletter, the *Triforium,* is the Academy tom-tom that keeps the membership informed of what is happening in the organization, what events are to take place, and what the status of the Academy programs are at that moment. Who will say what shall fall to the budget ax? Let him also say, how, and then produce a consensus. The savings by reducing publication to *Transactions* alone would not save enough to keep us solvent, and our losses in membership support would very likely outweigh any hoped-for gains.

Raising dues is the standard "easy-out" of a financial bind and it is also an "out" of another kind, namely membership drop-out. The gains of increased levy balanced against lost members and hence lost participation and revenue must be carefully considered. This course should be taken only if it solves the problem and only as a last resort.

The sum total of cost savings by discontinuing nonessential service programs now conducted by the Academy is roughly $200 to $300. The sum is small because the bulk of the cost is hidden in administration and not obvious as cash outlay. This brings us to staff salaries. These salaries by all odds are not even competitive in today's job market for the limited staff now conducting Academy business. Indeed we have not been able to increase salaries commensurate with the rise in cost of living. Whatever services we provide are those generated by the office staff.

The last drain on our budget is the Steenbock Center. We are for all intents and purposes locked into this facility by today's housing costs and appreciating real estate values. Maintenance costs of the Center would be about equal to rent charges for less desirable and certainly less functional quarters, *if* we were to sell the Center property.

* * *

So much for background. The basic option in my opinion and one under which we should have been operating from the outset is: That the Academy be financially supported by the State of Wisconsin. Historically the Academy was meant to be state supported and indeed it was in part until 1960. Each year prior to that time the Academy presented its annual program request (a pittance in relation to other requests) to the legislature and defended the request. The Academy request was not buttressed by great political clout and so was undoubtedly on the list of easy-to-cut items. Eventually by gentle but painful attrition the small budget was cut . . . completely.

With the advent of the Steenbock bequest to the Academy and later by the McCoy trust the need to seek state support through an annual hassle was diminished and all effort abandoned. Ironically this occurred at a time when Academy programs for the people of Wisconsin were increasing.

On the surface this could be regarded as a mistake, but if the Academy could support itself and eliminate the time consuming and arduous task of budget preparation and defense, then the move to become self supporting was correct. Although the monetary saving to the state was insignificant, *it served notice to the legislature that we were trying to help ourselves.*

The fact that we assumed a financial burden that had heretofore been in part a state responsibility does not abrogate legislative involvement in the welfare of the Academy as an agency serving the people of the state.

If it were at all possible, we would not now ask for renewal of state support and conceivably there may come a time when we will again become self sustaining.

We do not come with hat in hand to request help in difficult times but we respectfully ask for financial support because our cause is just.

We ask for no brick or mortar financing.
We ask for no support of our publications.
We ask for no funding of our programs.
We ask for no remodeling or physical expansion monies.
We ask for no land or real estate purchase.

What we request is a sum sufficient to maintain our physical plant and an adequate Academy staff. All other aspects of Academy functioning will be covered by membership dues and endowment proceeds. It is rare when any Academy or professional society can provide services or engage in programs for public benefit on membership dues alone.

The Wisconsin Academy of Sciences, Arts and Letters is 4th in size among 45 state academies and in prestige we rank near the top. We are not elitist in membership; anyone interested in our three major disciplines is welcome to join and participate.

We offer a forum for all who speak or write through our meetings and publications.

We have offered and hold open the offer to provide an unbiased sounding board on legislative or public policy discussions under consideration by our elected representatives at all governmental levels.

We will continue to provide programs of education and enlightenment to the people of Wisconsin (and elsewhere).

We will exchange our *Transactions* of the Academy with over 600 institutions in 60 countries promoting the progress, and the scholarly stance of our State in the fields of science, arts and letters.

We will strive to be self-supporting and frugal with public funding.

We will promote Wisconsin's people, its programs and its products by all means at our disposal.

* * *

The National Academy of Science is supported by the U. S. Government and performs a service to the nation by its response to problem solving and to policy solutions for the national welfare.

We ask only that the Wisconsin Academy be supported by the State of Wisconsin so we may likewise respond for the welfare of our State.

* * *

Thus my presidential address is ended. The epilogue that I pass on to fellow members of the Academy is this: I will appoint a committee to prepare an official position on this basic premise of state support and to develop a strategy on which to proceed. There are key people I have in mind and a tentative plan as a starting point for action, but the team is not complete. If we are to strive in this direction every last member will be asked to help. At the proper time when all is in readiness the program will be made a matter of Academy record and membership participation will be solicited for support in an effort to enlighten our legislature on the necessity and wisdom for providing state support.

So important is this effort that it must not rest solely with a small committee of dedicated people. The Academy rank and file must become involved. The need is urgent and our cause justified!

PALEOLATITUDE AND PALEOCLIMATE

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Abstract

In light of large-scale displacements of continents through time, restoration of paleolatitudes is critical to any paleoclimatic reconstruction. Paleomagnetic studies over the past two decades have provided estimates of paleolatitude that are more and more widely accepted. It was important, however, to test those estimates with independent geologic evidence—especially for pre-Permian time for which paleomagnetic data is less satisfactory. On the other hand, geologic coupled with paleomagnetic evidence should provide powerful constraints for paleoclimatic interpretations.

Paleomagnetic data suggest a Paleozoic equatorial position for most of North America with a progressive relative counterclockwise rotation of the continent of about 60°. Long-recognized reef and species-diversity patterns support a Paleozoic low latitude, and Ordovician and Devonian volcanic ash fallout by trade wind dispersal is consistent with the paleomagnetically-indicated equator positions. Mid-continent early Paleozoic paleocurrent and conglomerate size-rounding data also agree with a tropical location characterized by episodic violent storms. And Permo-Triassic plant and evaporite evidence is consistent with both latitude and terrain restorations. As North America moved northward (and more counterclockwise) since the Triassic, its central part came into the westerly wind belt as evidenced by fallout of volcanic ash from the Cordillera. Most post-Triassic geologic indicators of humid-arid conditions, paleocurrents and oxygen-isotope data, are consistent with latitudinal and terrain restorations.

INTRODUCTION

In 1958, when I began teaching, enough paleomagnetic evidence of ancient latitudes had accumulated that the student of earth history could hardly ignore it. Yet, there were large gaps in the data and some untidy anomalies. Many, if not most, geologists doubted the results, perhaps because shifting poles or continents seemed non-uniformitarian. But by the mid-sixties, the data had begun to show enough of a systematic pattern of latitudinal change that one could begin to consider a number of geologic implications of the paleomagnetic results in addition to continental drift. Indeed, it became intriguing to compare—and even test—the paleomagnetic data against sedimentologic and paleontologic evidence of latitude. While paleoclimatology still seems more art than science, it is nonetheless fruitful to examine the consistency of phenomena.

The distributions of ancient reefs, evaporites, tillites, coal, certain fossil plants, red beds, and presumed eolian desert deposits have long been used to try to interpret paleoclimatic zones and even paleolatitude (e.g. Köppen and Wegener, 1924). Clearly, all of these geologic phenomena should provide tests of the paleomagnetic data. In 1956 Shotton and in 1960 Opdyke and Runcorn presented the first comparisons of wind-influenced cross bedding orientations with paletomagnetically-indicated latitudes (see also Opdyke *in* Nairn, 1961, and *in* Runcorn, 1962). Then Eaton in 1963, Powers and Wilcox in 1964 and Wilcox in 1965 showed that fallout distributions of volcanic ash could reveal prevailing paleowind directions, adding still another dimension to paleoclimatic and paleolatitudinal analysis. About 1960 I began cataloguing these diverse kinds of data on paleogeographic maps (Dott and Batten, 1971).

To many the present large mass of paleomagnetic evidence of drastically different past latitudinal positions of continents may make further comparison of paleomagnetic and paleoclimatic data seem redundant. However enough skepticism exists (e.g. Meyerhoff and Meyerhoff, 1972; Stehli, 1973) to warrant a concise, up-dated assessment. Although this paper deals almost exclusively with North America, the approach is universally applicable. My objective is not to prove or disprove continental drift, but only to assess *consistency* of unlike data. Distributions of reefs, evaporites, red beds, coal and the like have been catalogued before (e.g. Nairn, 1961; Runcorn, 1962, Schwarzbach, 1963; Dott and Batten, 1971 and 1976). Therefore, more attention is given here to paleowind indicators and to a few stratigraphic intervals that have not previously received adequate treatment.

Working Assumptions

Certain climatic assumptions provide a background. We must first assume that a significant temperature difference has always existed between the poles and equator simply as a consequence of the difference in angle of incidence of solar radiation. The intensity of the pole-equator gradient has almost certainly varied through time, and such variations would have greatly affected world climate. This thermal gradient, coupled with the rotation of the earth and the positions of land masses, controls the first-order patterns of atmospheric circulation. One consequence of variations of the pole-equator gradient is the positioning of subtropical high pressure cells. With a stronger gradient, these highs are pushed equatorward, whereas with a weaker gradient they move somewhat poleward.

The general climatic importance of the ratio of land to sea (or continentality) was appreciated as early as Lyell's time. It is well known that the relative area of sea and land greatly affects the overall heat budget of the earth because of the 10-15 percent difference in albedo of land versus water. Moreover, being fluid, the seas can transport heat from low to high latitudes. It follows that the location of a pole in a continent or a restricted sea (such as the present Arctic Ocean) will be much colder than a pole located in an open ocean area.

The spin of the earth and the resulting Coriolis effect, allow steady trade winds on either side of the equator to be assumed for all times. The Westerly wind belts probably also have always existed, but seemingly they were more variable than the trades because of variations of the pole-equator temperature gradient and of land masses. Landmasses greatly influence second-order atmospheric circulation patterns by localizing or blocking the more or less permanent high and low pressure cells. Mountainous barriers obviously may produce strong rain shadows.

Paleomagnetic Latitudinal Restorations for North America

Latitudinal shifts of North America are indicated by paleomagnetic data for the past 700 million years (Fig. 1). The paleoequators have been up-dated from those of Dott and Batten (1971 and 1976). Locations are better established for some ages than for others, nonetheless, the counterclockwise rotation and northward motion of the continent presents an impressively systematic picture. Only the details of exact position for the more poorly controlled periods remain to be documented.

Paleoclimatic Phenomena Compared With Paleomagnetic Evidence

Working backward through time, let us compare some climatically sensitive geo-

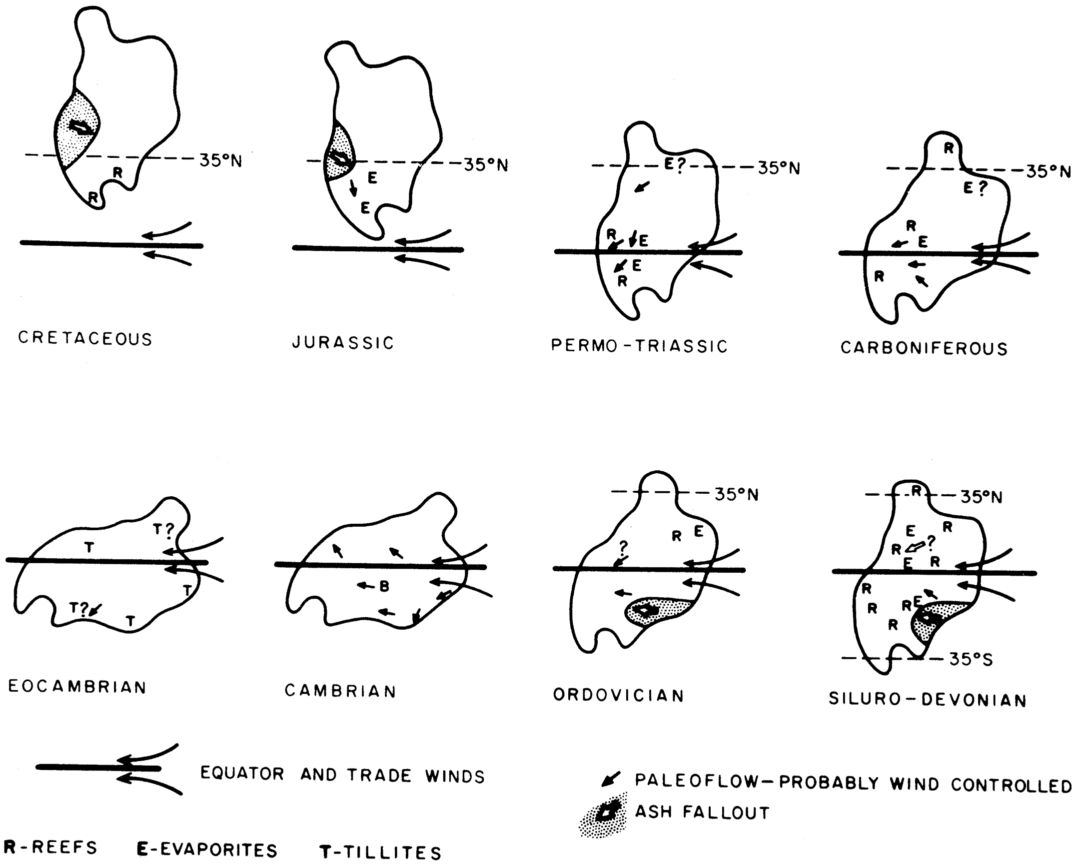

Fig. 1. Ancient latitudinal positions of North America based upon paleomagnetic data compared with sedimentary data. Note systematic counterclockwise rotation and northward shift of the continent. (Paleomagnetic results from: Irving, 1964; McElhinny, 1973; Hicken, and others, 1972; Van der Voo and Williams, 1975; French, and others, 1975; Proke and Hargraves, 1973; McElhinny and Opdyke 1973; Van der Voo and French, 1974. Sedimentary data after Dott and Batten, 1971 and 1976, who include detailed maps and references.)

logic phenomena with the paleomagnetic latitudinal data to see whether or not the two independent types of evidence agree paleogeographically. The fallout patterns of late Cenozoic (especially Pleistocene) volcanic ash erupted in the Cordillera (Wilcox, 1965) and paleontologic evidence of a rain shadow effect east of the mountains agree with the present location of that region in the mid-latitude westerly wind belt (Dott and Batten, 1971, chapter 14). The same is true also for Cretaceous and Jurassic ash fallout (Fig. 1; Slaughter and Earley, 1965). Cretaceous humid, subtropical plant types (Arnold, 1947; Andrew, 1961) and oxygen isotope evidence for warm sea temperatures of 20°-25°C (Lowenstam and Epstein, 1959) are consistent with a lower latitude (Fig. 2). Cretaceous plants apparently adapted for humid conditions in the present Rocky Mountain region, however, seem anomalous as they grew leeward of the rising Cordilleran mountainous mass. According to Millison (1964), the lack of a clear rain shadow here is the result of humid air flowing from the southeast over the adjacent Cretaceous epeiric seaway and along the eastern front of the Cordillera. In light of the probable paleolatitude, however, it appears more probable that moisture was acquired from that seaway by winds of the sub-tropical high pressure system flowing south along the mountain front (Fig. 2). However, fine ash blown higher into the atmosphere would be blown straight east by upper atmosphere winds.

The latest Jurassic Morrison Formation of the western United States was deposited to the lee of the embryonic Cordilleran mountains (Fig. 3). The Morrison accumulated at about 30°-40° N latitude; it was within a westerly wind belt as indicated by volcanic ash that could only have blown from the west. Oxygen isotope studies of shells from underlying Upper Jurassic (as well as overlying Cretaceous) marine rocks indicate warm ocean temperatures around 20°-25°C (Bowen, 1961), at least 10° warmer than is typical of that latitude today. Moreover, Bowen (1961) argues that the maximum latitudinal surface Jurassic sea water temperature gradient then was only about 20°C as opposed to 60°C today. Local evaporites in the same underlying strata also indicate high evaporation potential.

Sedimentary facies, petrography, and paleocurrent data prove that the Morrison was deposited on an eastward-sloping, low coastal plain; Dawson (1970) estimated the

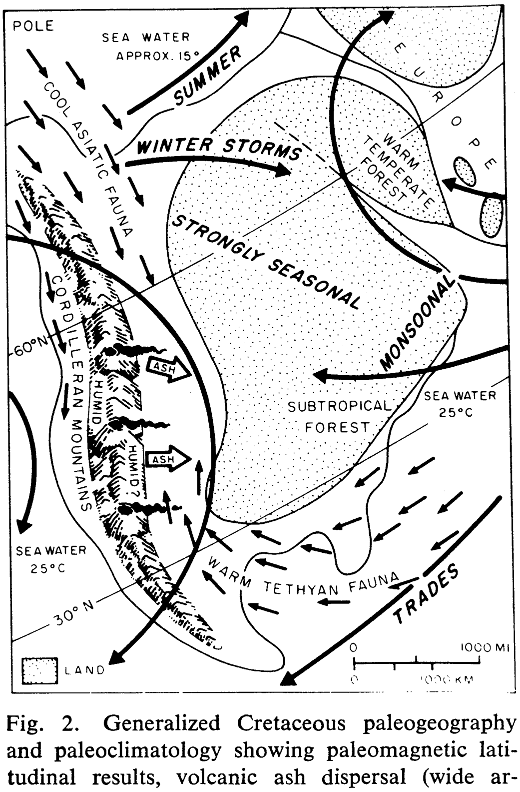

Fig. 2. Generalized Cretaceous paleogeography and paleoclimatology showing paleomagnetic latitudinal results, volcanic ash dispersal (wide arrows), oxygen isotope results, and paleobotanical evidence. Superimposed are the expected atmospheric circulation patterns; subtropical highs appear at higher latitudes than today because of a lesser pole-equator temperature gradient. Small arrows indicate dispersal of warm- and cool-water faunas. Sea water temperatures are obtained from oxygen isotope studies. (Modified after Dott and Batten, 1976). Compare with Figure 1.

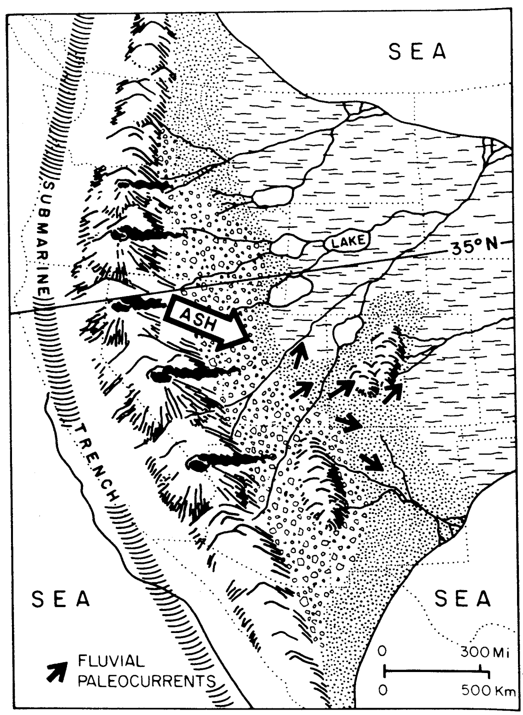

Fig. 3. Paleogeography during deposition of the nonmarine Morrison Formation clastic wedge in the western United States. The formation was deposited on a coastal plain sloping eastward from the rising Cordilleran volcanic arc whence ash was carried by westerly winds. (Adapted from Dawson, 1970 and Dott and Batten, 1971; see latter, Fig. 13.19, for ash fallout.)

gradient to have been of the order of 0.5-1.0 m per km. Widespread fresh-water limestones attest to a rather wet landscape, and the large herbivorous dinosaur fossils for which the formation is famous suggest at least moderate humidity. Yet, coal is almost totally lacking and fossil plant material (chiefly cycad wood and reeds) is rare. Why? Dead plant material must have been thoroughly oxidized at the soil surface, which seems consistent with the abundance of red- and yellow-colored sediments. Either the Cordilleran mountains were not yet high enough to form a strong rain shadow, or the Morrison coastal plain was relatively dry except along broad river valleys. Dawson (1970) suggested a strong seasonal distribution. This was based upon the apparent thorough oxidation of vegetation, well-developed growth rings in fossil wood, and the texture of fluvial conglomerates interstratified with the dominantly fine-grained Morrison sediments. To move the largest cobbles (13 cm), which are now at least 200 km from their western upland source, maximum shear velocity must have been at least 50 cm per second, while the maximum river velocity near the water surface could have been roughly 200-600 cm per second.[1] Such large velocities seem surprising for the apparently low gradient of the Morrison coastal plain; the most probable explanation is that the coarse gravel was moved only incrementally in wide, braided channels during seasonal flooding.

Westerly winds are also indicated for latest Triassic to earliest Jurassic time in the western United States by the orientations of large-scale cross bedding in the Navajo and related sandstones. Whether this famous sandstone represents entirely eolian or partly shallow marine dunes—both of which have been claimed—they must have been deposited under the influence of the prevailing westerly winds of that time as first suggested by Poole (1957).[2] If the Navajo is, in fact, largely eolian, as I now believe, it would seem to represent a large dune field

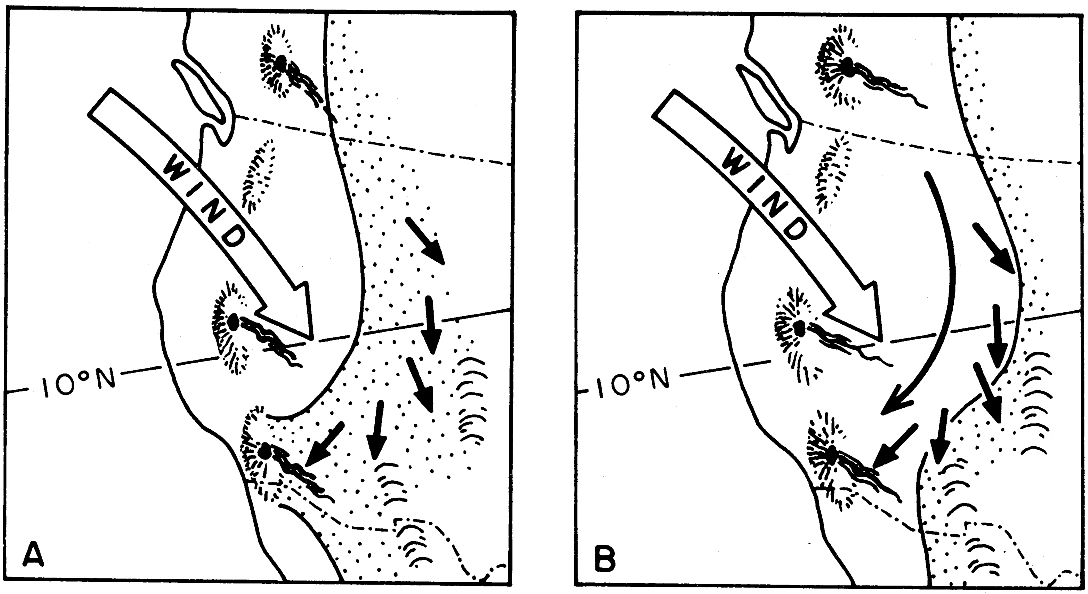

Fig. 4. Alternate paleogeographic interpretations of the Navajo Sandstone. A. Classic hypothesis of a vast eolian dune field, for which the evidence seems strongest; B. Hypothesis of a combination of shallow marine and coastal eolian dunes (Stanley, Jordan and Dott, 1971). In either case westerly winds apparently controlled sand dispersal.

formed by onshore winds from the northwest (Fig. 4A). In its western extent, some of it appears marine and one can infer that nearshore dispersing currents were induced by westerly winds, with a strong southerly longshore drift component (Fig. 4B), (see Stanley, Jordan and Dott, 1971; Dott, 1979).

For Permo-Triassic times, both the paleomagnetic and geologic data bearing upon climate are among the most complete. Tropical to sub-tropical latitudes for North America are indicated by paleomagnetism with the paleoequator (Fig. 1) almost exactly coincident with that inferred by Wegener a quarter of a century before any paleomagnetic data existed. The consequences of expected atmospheric circulation patterns for Permo-Triassic North America can be tested geologically (Fig. 5). Paleowinds over the western United States as indicated by widespread Permian cross bedded sandstones (whether eolian or very shallow marine) conform well with expected trade wind orientations. Extensive evaporites in the central United States conform well with a down-wind tropical continental margin to the leeward of high mountains. Permian plants with features adapted to aridity occur in Arizona, while the inferred humid-tropical lowland plants associated with Pennsylvanian coals had given way to drought-tolerant gymnosperms in eastern United States and humid-temperate forms in East Greenland (Frederickson, 1972). But, with Africa and Europe adjacent to eastern North America how could eastern America have been humid? One would expect a dry interior of the Gondwana supercontinent like central Asia today? Apparently the Tethys seaway and epeiric seas over central Europe during part of Permian and Triassic times supplied moisture to westerly-blowing trade winds (Fig. 5).

The Carboniferous latitude of North America seemingly was similar to that of the Permian. Widespread Mississippian organic

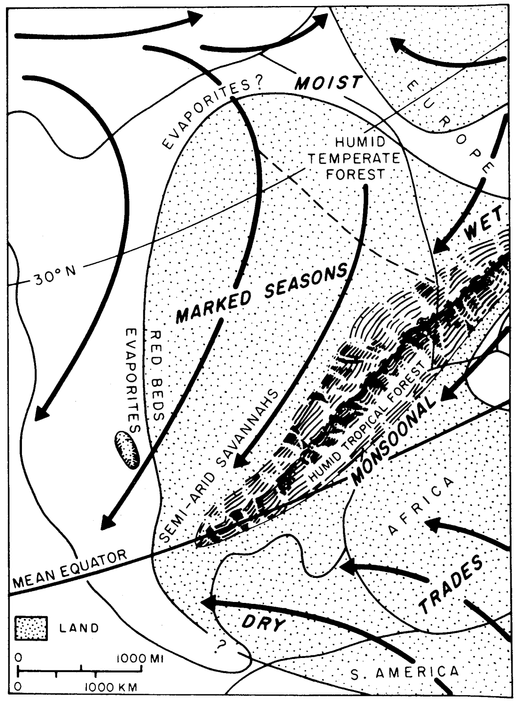

Fig. 5. Generalized Permo-Triassic paleogeography and paleoclimatology showing comparison of equator positions from paleomagnetism with sedimentary and paleobotanical evidence (see also Fig. 1). Superimposed are the expected atmospheric circulation patterns with sub-tropical highs shifted poleward for the same reason as in Fig. 2. (After Dott and Batten, 1971 and 1976).

reefs are consistent with a low latitude location, and trade winds apparently influenced the deposition of cross bedded Pennsylvanian quartz sandstones over the western United States as it did later in the Permian (Fig. 1). Unlike Permian time, however, no strong rain shadow is evident across the continent, for humid-tropical to sub-tropical lowland swamp forests cloaked the eastern interior. This suggests that the Appalachian mountains were not yet very high. Nonetheless Mississippian evaporites of the Williston Basin and Pennsylvanian ones in Utah indicate an evaporation potential that was significant where marine circulation became restricted.

The abundance and widespread distribution of organic reefs in Devonian and Silurian times long ago provided arguments for a low-latitude location of North America, although a good case also could be made for a weaker pole-equator temperature gradient and a generally warmer, more uniform climate during a time of small, low continents (Dott and Batten, 1971, Fig. 11.46 or 1976, Fig. 13.24). Major evaporites attest to high evaporation potential and areas of restricted circulation. The inferred tentative windward side of some of the Canadian reefs (Andrichuk, 1958) would face into the trade winds expected for the restored paleoequator. Finally, Late Devonian volcanic ash distribution over the eastern United States conforms to fallout for winds expected for the paleoequator (Fig. 1).

For the Ordovician, ash fallout from volcanic events in the Appalachian region conforms well with trade winds expected for the apparent paleoequator (Fig. 1). What little is known of the dispersal patterns for the St. Peter Sandstone also conforms to such

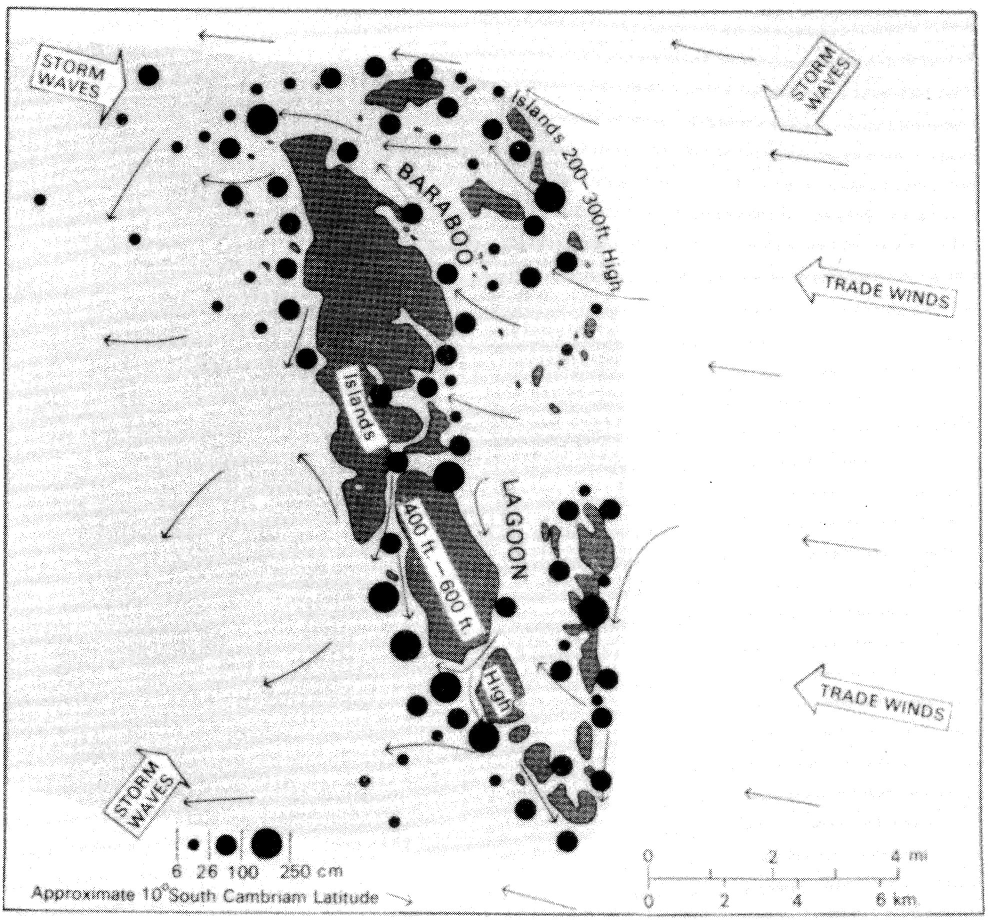

Fig. 6. Paleogeographic restoration of the middle Late Cambrian Baraboo (Wisconsin) islands according to paleomagnetic evidence for a southern tropical setting. Trade winds inferred from regional cross bedding orientations in shallow marine sandstones. Episodic storm waves must have approached from all sides judging from the uniform distribution of largest rounded quartzite clasts (dots). Fine pebbles were dispersed to the left (lee) by normal currents following storms (shaded area). (From Dott, 1974.)

winds (Dapples, 1955; Dott and Roshardt, 1972). Finally, the great species diversity and sheer abundance of Ordovician marine faunal elements is consistent with a tropical to subtropical setting.

Cambrian strata of the central United States provide some additional evidence for a low latitude for early Paleozoic North America. The paleocurrent pattern, for which there is abundant data, conforms to trade-wind-driven shallow marine currents expected for the paleomagnetically indicated equator. In Wisconsin, the presence of Cambrian islands that shed coarse gravel has provided an unusual opportunity to estimate the magnitude of ancient storm waves and also to contrast effects of day-to-day processes with those of so-called rare events. A broad range of gravel clast diameters from 1 cm granules up to 8 m boulders occurs, but there is no rounding of boulders larger than 1.5 m. Clearly the waves that pounded Cambrian sea cliffs around Baraboo, Wisconsin were not capable of moving larger boulders frequently enough to abrade them. Two slightly different approaches are available for making quantitative estimates of the Cambrian storm wave heights.[3] Both results indicate that breakers at least 8-10 m high crashed upon the islands and tumbled boulders up to 1.5 m in diameter with moderate frequency; almost certainly still higher waves developed on rare occasions. Rounded boulders occur all around the Baraboo islands, thus rare-event storm waves must have approached from all directions, not just from the apparent normal trade winds direction suggested by paleocurrent data (Fig. 6). Trade winds themselves, though very steady, are not sufficiently strong to generate the large waves required to move boulders. Therefore, large storms are indicated, and, while other types are possible (e.g. mid-latitude Nor'easters on our present Atlantic coast), tropical storms seem most probable in light of the conformance of the regional paleocurrent pattern with the paleomagnetically indicated latitudinal position of Wisconsin (Fig. 1).

Conclusions

Comparison of climatically-sensitive geologic phenomena with paleomagnetic evidence for ancient latitude presents generally consistent restorations. North America apparently was dominated by Trade Winds throughout Paleozoic time, but moved into the Westerly wind zone during Mesozoic and Cenozoic times. For some eras in North American (e.g. late Mesozoic, Permo-Triassic and Late Cambrian times), a satisfying degree of completeness of paleoclimatic restoration is possible. At best, however, such restorations are largely qualitative. Not all available data provide a clear picture; the hardly disputable Eocambrian glaciation is a case in point. Tillites or tilloids are known today in Eocambrian strata from all continents except Antarctica. Indeed, their widespread distribution is the problem, for they seem to occur at all paleolatitudes. Was the climate so rigorous and completely unzoned that glaciation occurred from pole to equator (Fig. 1)? At present the Eocambrian paleoclimatic data cannot be satisfactorily reconciled with paleomagnetic evidence, which points up the need for additional comparative studies of both phenomena.

Acknowledgements

My work and that of several former students that bears upon this paper has been supported by grants from the Graduate School of the University of Wisconsin, Madison, from funds donated by the Wisconsin Alumni Research Foundation and the University-Industry Research Program. Rob Van der Voo of the University of Michigan was extremely generous in helping me update the paleomagnetically indicated paleolatitudes, and colleagues in the Department of Meteorology, at the University of Wisconsin, notably R. A. Bryson, E. Wahl, and J. E. Kutzbach, have been of great help over the years in trying to educate me on climatology. I have drawn upon the thesis research of James C. Dawson, William M. Jordan and Kenneth J. Stanley, some of which has not been published. Their work and many stimulating discussions with them are gratefully acknowledged.

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Notes

[1] Bed shear velocity (U*) was estimated from the relation $U^* = \sqrt{\tau/\rho}$ where τ is shear stress (derived from the Shield's Diagram) and is fluid density. The lower limit for maximum channel velocity above the bed was determined from the Hjulstrom-Sundborg graph, while the upper limit was estimated from the relation $\left(\frac{\bar{U}}{U^*} = \sqrt{\frac{8}{f}}\right)$ assuming a value of about 0.05 for f for a gravelly bed. (See Blatt and others, 1972). This equation is suspect for hindcasting channel flow, however, because the friction factor (f) is based upon flow in pipes; it is very sensitive to bedforms and hydraulic radius as well as to grain size and velocity in channels.

[2] Some prominent cross bedded sandstones long interpreted as eolian have been reinterpreted as shallow submarine sand wave deposits like those of the present Georges Bank, North Sea, Irish Sea and English Channel (Stanley, Jordan and Dott, 1971). When they were first interpreted to be eolian, the existence of underwater dune forms was unknown. Because in shallow epeiric seas currents are so strongly influenced by prevailing winds, the orientations of cross strata formed in submarine dunes also should reflect such winds unless tidal currents (or the Ekman effect) completely masked the wind's influence on sand dispersal. The thorny issue of environment of these sandstones is sidestepped in this paper because none of the cross bedded sandstones in question show any definitive tidal features.

[3] Breaker height can be estimated from experimental data for breakwater design derived in large wave tanks, and from empirical equations relating threshold velocity to boulder diameter and velocity to breaker height:

$$U_t = 9d^{1/2} \text{ and } C_b = 2U_t \text{ and } H_b \approx \left(\frac{C_b}{8}\right)^2$$

Where U_t is threshold velocity to move boulders of diameter d; c_b is solitary wave velocity at the point of breaking, and H_b is height of breaker. (Dott, 1974).

SOILS AND SURFICIAL GEOLOGY OF FOUR APOSTLE ISLANDS

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Abstract

The soils and surficial geology of Rocky, Oak, York, and Raspberry Islands, members of the Apostle Islands group, were surveyed in 1976 and 1977.[1] The considerable diversity of environmental conditions affecting soil development has given rise to complex soilscapes. Most common on Rocky, York, and Raspberry Islands are fertile deciduous forest soils (Eutroboralfs of the Alfisol order) formed in deposits of fine-grained glacial and glacio-lacustrine material. On Oak Island the soils are primarily sandy Podzols (Harplorthods of the Spodosol order) formed in coarse beach deposits more than one meter thick. Since moderate slopes of 5 to 20% provided the best opportunity for thick sand and gravel accumulations in the ancient beach zones, the pedologic uniqueness of Oak Island is explained by the sloping surfaces it presented to subsiding post-glacial lake levels.

Introduction

The Apostle Islands are located in the northernmost part of Wisconsin, clustered at the tip of the Bayfield Peninsula. Except for Madeline Island, the Apostle Islands are accessible only by boat. Isolation of the islands has protected some of the best examples of wilderness remaining in the eastern United States. Although logged as recently as 50 years ago, the islands still harbor some stands of mature northern mesic forest. Many species of native animals also inhabit the islands and are relatively undisturbed.

In recognition of the special quality of the recreational resources present in the area, the U. S. National Park Service has been assigned jurisdiction over most of the islands (see Fig. 1). To provide a basis for determining the recreational carrying capacity the Park Service launched a program of resource evaluation studies. Results of study of soils and surficial geology of Bear Island were reported by Kowalski (1976). This paper presents observations made during two field seasons on York, Raspberry, Rocky, and Oak Islands. Descriptions and maps of the major soils are supplemented with a discussion of the environmental factors which influenced soil development. Features of the soil landscapes and an important relationship between soils and topography are also discussed.

Geologic History of the Apostle Islands Area

Although tectonically stable at present, the Lake Superior region in early Precambrian time (about 3 billion years ago) was a region of active mountain building. The crystalline rocks which constitute the bedrock in northern Wisconsin and most of Canada are the fluvially and glacially eroded remnants of the once broad mountain belt. Further tectonic activity opened a huge trough, or graben, which eventually filled with thick deposits of sand and gravel

[1] Work was done under the general direction of Prof. R. T. Brown, Michigan Technological University, and funded through that institution by the U. S. National Park Service. Work was guided by Prof. F. D. Hole, University of Wisconsin-Madison. Terminology is from *Soil Taxonomy* (Soil Survey Staff, 1975).

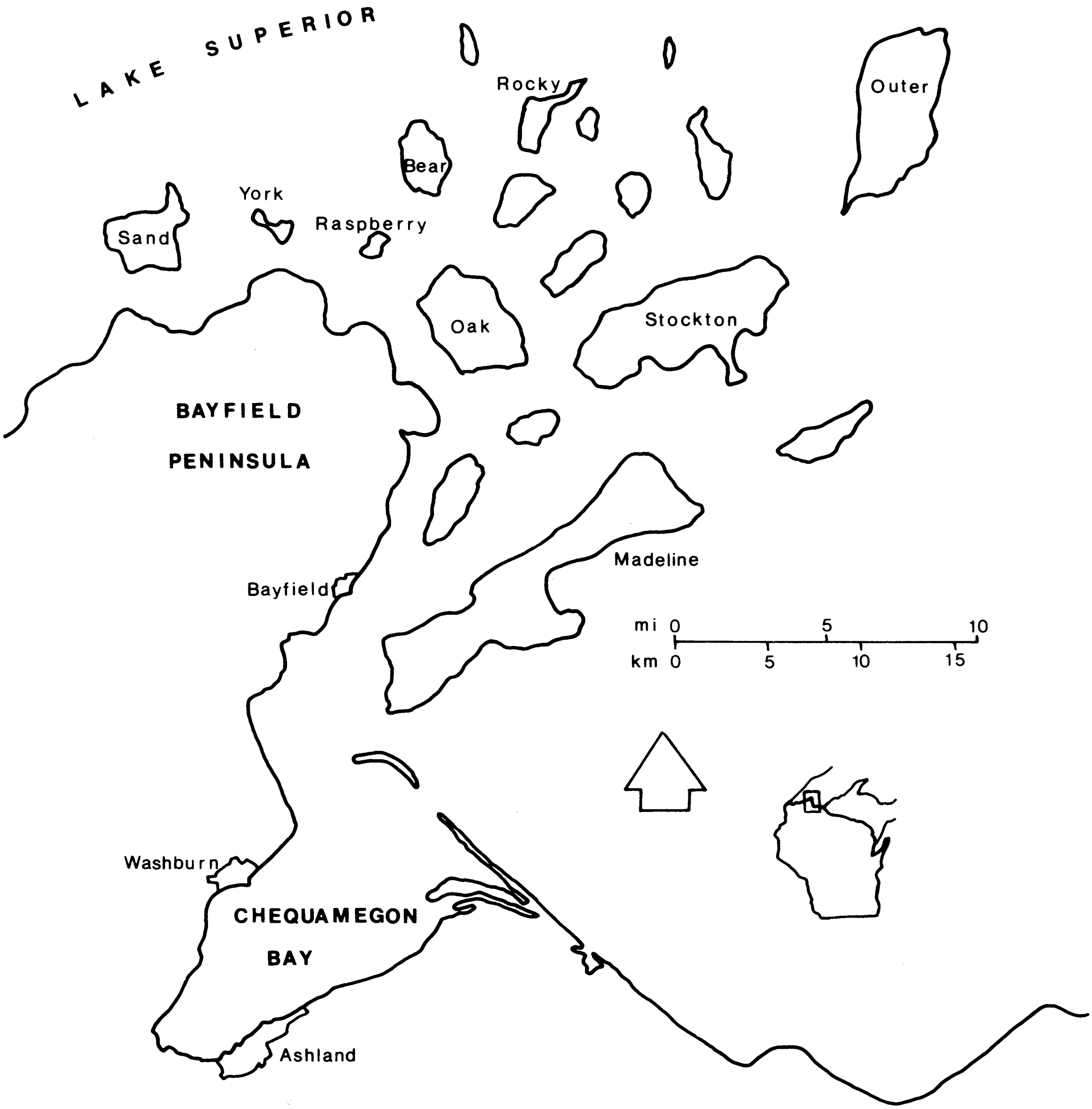

Fig. 1. The Apostle Islands and the Bayfield Peninsula of northern Wisconsin.

eroded from the nearby highlands and deposited in the Precambrian sea (Martin, 1965). Excavation of some of the sandstone over many millions of years by rivers and glaciers created the Lake Superior basin. The Bayfield Peninsula and all of the Apostle Islands are underlain by portions of the remaining sandstones belonging to the Bayfield group.

Much of the Lake Superior basin was hollowed out during the Pleistocene Epoch—the most recent 3 million years of geologic history. Continental glaciers repeatedly advanced southward from Canada, following and deepening the lowlands in which the Great Lakes now lie. Evidence from the most recent glacial advance indicates that after ice filled the Lake Superior basin the Bayfield Peninsula upland forced the growing ice mass to split. The Superior lobe

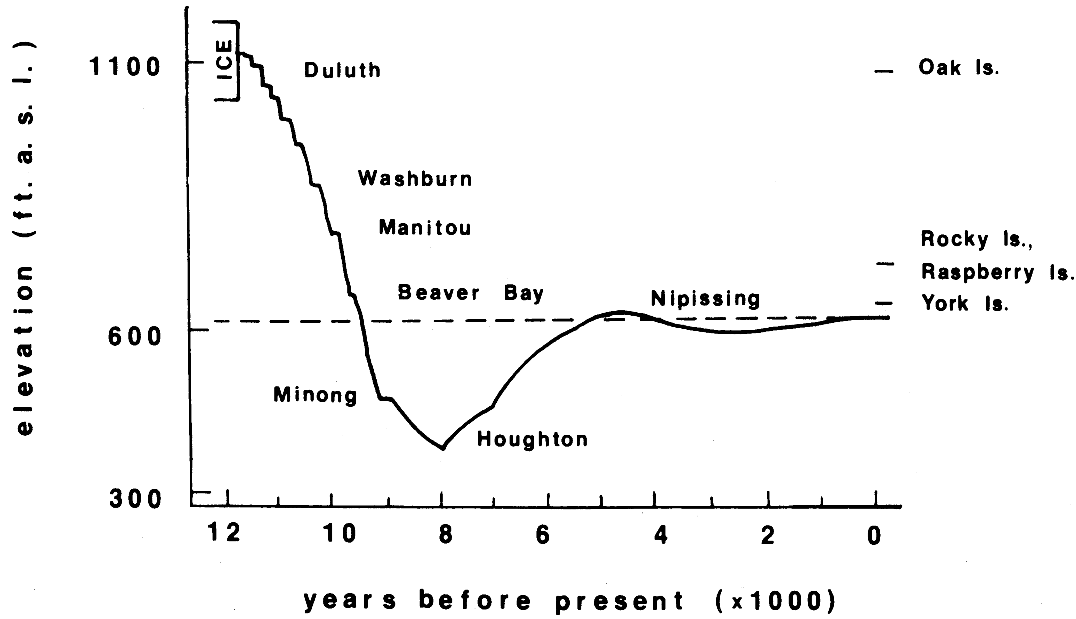

Fig. 2. Postglacial changes in the level of Lake Superior; names of some abandoned shorelines are given. The topmost elevation of the four islands studied is given at right (after Farrand, 1969).

flowed westward while the Chippewa lobe filled Chequamegon Bay and spilled into what is now the Chippewa River basin. The Apostle Islands were probably separated from the mainland by glacial enlargement of preglacial river valleys (Collie, 1901; Irving, 1880). Its interlobate position caused the Bayfield highland to receive great volumes of glacial debris. In general, the current land surface of kettles, kames, and moraines is more than 120 m (400 ft) above the bedrock. Some of the till deposited by the ice is very sandy and acid, but other till bodies are very clayey and somewhat calcareous. The contrasting source materials, Bayfield sandstone and Pleistocene lake sediments, are responsible for the differences.

Retreat of the last continental glacier began about 12,000 years before the present (BP). As the ice mass wasted back into the Lake Superior lowland, meltwater accumulated between the ice front and the southern rim of the basin. Glacial Lake Duluth stabilized at about 329 m (1,085 ft) above sea level and drained south at Solon Springs, Wisconsin into the St. Croix and Mississippi Rivers. These conditions lasted until about 11,000 years BP (Farrand, 1969, p. 195), at which time all of the Apostle Islands were submerged. The ice mass then wasted rapidly, opening lower eastern outlets into the Lake Michigan basin. Subsequent rapid lake level decline was marked by only minor halts until about 8,000 years BP, when the low-water Houghton stage, 114 m (375 ft) above sea level, was reached. In about 3000 years the water level fell about 210 m (700 ft), for an average rate of 70 cm (2.33 ft) per decade, or almost 8 cm (3 in) per year (Fig. 2).

During the first part of this period of lake level recession all of the Apostle Islands emerged. The abandoned strandlines visible on the islands, including the Highbridge, Moquah, Washburn, Manitou, and Beaver

Bay shorelines named by Farrand (1960), were formed between 11,000 and 8,000 years BP. At the time of the Houghton stage water levels were so low that the Apostle Islands were part of the mainland. Buried peat found in places beneath 12 m (40 ft) of water and 4 m (13 ft) of sand marks this lake level minimum among the Apostle Islands (Taylor, 1931).

Lake level gradually rose for the several thousand years which followed as isostatic rebound lifted the outlet at Sault Ste. Marie, Michigan. The Nipissing stage, only slightly higher than the present water level, was reached at 5,500 years BP (Saarnisto, 1975, p. 312). Beaches formed at that time are difficult to distinguish from current Apostle Islands beaches, as they are only 1 m (3 ft) higher than the present lake elevation of 182 m (602 ft) above sea level (Farrand, 1969).

As soon as dry land became available, colonization by tundra and boreal forest plants and animals began. Spruce was the dominant tree in these early woodlands, but as climate ameliorated, spruce was gradually superceded by pine. Eventually the transition was made to the present northern mesic forest, which contains both hardwoods and conifers (Saarnisto, 1974; Maher, 1977). Thus Quaternary geologic history provided diverse initial conditions for development of the soils presently found on the Apostle Islands.

Environmental Factors Affecting Soil Formation

Initial Material

The recent geologic history of the Apostle Islands is one of continental glaciation, inundation by postglacial lake waters, and reexposure. In most places, deposits of glacial till are covered by lake sediments of varying thickness. High water levels in the Lake Superior basin and copious amounts of sediment from melting glacial ice promoted deposition of clay and silt in deep water and coarser-textured material in shallows and on beaches. Typically one would expect to find lacustrine sediments deposited in a vertical sequence which coarsens upward because lake levels were falling, but in many places there are only small amounts of sand or gravel overlying clayey material. Some soils formed in thin coarse deposits over fine-grained lake sediments or till (which are often difficult to tell apart), while other soils formed in thick sand and gravel deposits.

Surface modification of the islands, since their emergence from receding glacial lake waters, has been chiefly by stream activity. On Oak Island, deep ravines are prominent. In the ravine bottoms one finds small alluvial terraces and narrow incipient floodplains.

Time

All soil formation presently evident on the Apostle Islands has taken place in the last 11,000 years. As soon as the topmost points on the islands were exposed, weathering, plant colonization, and soil formation (pedogenesis) began. The only major variation results from recent increasing emergence of the lower parts of the islands. Soil formation has proceeded for a longer time on the top of Oak Island than on low-lying York Island, for example. However, this potential time difference is not very great (Fig. 2). Rapid lake level recession exposed all land elevations in about 2,000 years. The 9,000 years that have since elapsed have been sufficient to obscure any time-related differences between the soils at high elevations and those on the lower flanks of the islands. This is particularly true for Spodosols, which may be formed in only a few hundred years (Buol, Hole, and McCracken, 1973, p. 254). On Oak Island, spodosols with well-cemented ortstein horizons, indicators of advanced pedogenesis, were identified throughout the full range of elevations.

Formation of soil horizons depends on downward water movement. Soil development has not proceeded as far on steep slopes where much water runs off as on more nearly level areas where most water percolates into the soil. Thus, rates of pedogenesis are different in different landscape positions.

Topography

There are considerable differences between islands with respect to topography. Most of the 22 islands in the group are relatively level and low-lying; York, Raspberry, and Rocky Islands are good examples. On these islands runoff is limited and drainage networks are poorly developed. Most rainfall and melted snow must move downward. Such infiltration is often slow, as lacustrine clays are frequently near the soil surface where they impede drainage. The subdued relief provides relatively uniform microclimatic and hydrologic environments for plant growth and soil formation.

Oak Island, on the other hand, is comparatively rugged. Although it is less than 19 km^2 (8 mi^2) in area, it has almost 150 m (500 ft) of relief. The sloping landscape is cut by numerous deep ravines. A diversity of microclimates, microhabitats, and soils matches the complexity of landform.

Climate

Although the Apostle Islands, at nearly 47° latitude, constitute the northernmost land in Wisconsin, the climate is more temperate than in many areas to the south. The moderating influence of Lake Superior causes cool summer temperatures, relatively mild winter temperatures, and growing seasons of more than 150 days—much longer than in most of northern Wisconsin (Finley, 1975). Like much of Wisconsin the area of the Apostle Islands receives about 0.75 m (30 in) of precipitation each year. Most of this precipitation falls as rain in the summer when convectional storms are most frequent. By comparison, winters are relatively dry, although snowfall usually exceeds 1.75 m (70 in) (Finley, 1975). Northwesterly winds bring cold, dry Canadian or arctic air which gains moisture from Lake Superior and occasionally drops snow. Springs and autumns are moderately wet. In summary, the Apostle Islands experience moderately long growing seasons and receive enough moisture to provide significant downward movement of water for leaching.

Organisms

The dominant plant communities on the Apostle Islands are northern mesic forests (Curtis, 1959). Although heavily logged in the early 20th Century, the second and third growth forests appear similar to presettlement composition. Important tree species are sugar maple (*Acer saccharum*), hemlock (*Tsuga canadensis*), yellow birch (*Betula lutea*), paper birch (*Betula papyrifera*), and basswood (*Tilia americana*). Locally common are red oak (*Quercus borealis*), white pine (*Pinus strobus*), white cedar (*Thuja occidentalis*), and balsam fir (*Abies balsamea*). Red oak and hemlock were selectively logged during the 1930's (Beals and Cottam, 1960). While conifers and hardwoods make up the canopy, the forest floor is usually heavily populated with sugar maple seedlings. The Canadian yew (*Taxus canadensis*) was once a major ground cover species, but over-browsing by deer has made it rare on some islands (Beals, 1958). Scarcity or absence of deer on some of the smaller islands has allowed yew to remain dense. The importance of coniferous and hardwood vegetation and litter to soil development is discussed by Buol, Hole, and McCracken (1973). Also important on the Apostle Islands is the high frequency of wind-throw. When trees are uprooted by strong winds, tip-up mounds are formed. This process creates depressions and mounds and churns the soil locally. The impact of the process on soil horizon development has been studied by Gaikawad and Hole (1961) and Graumlich (1978).

SOILS

Since the landscape of the Apostle Islands is geologically young, soil forming processes have had relatively little time to work. Consequently, soil development has usually affected no more than the upper 1.3 m (4 ft) of surficial material. Soil profiles are shallow. As stated earlier, the climate provides sufficient water to ensure soil leaching, a regime conducive to downward translocation of nutrients and organic colloids as part of the process of podzolization. Similar downward movement of colloidal clay is termed lessivage (Buol, Hole, and McCracken, 1973). Leaching occurs in most humid climates. If nutrient-rich litter and organic matter is not continually added to the soil surface, podzolization will create a Spodosol (Podzol), an infertile soil. Spodosols are commonly found associated with coniferous vegetation and loamy or sandy parent materials.

Most evergreen trees produce nutrient-poor, acid litter. Coarse-grained parent material is easily leached and is incapable of retaining many nutrients necessary for plant growth. The profile of a Spodosol usually has an ashy grey, well leached zone at the top over a dark brown horizon of illuvial organic matter, iron and aluminum oxides, and some colloidal clay. Beneath that spodic horizon the concentration of illuviated materials decreases and the brown color fades. At depths of 1 m or more the geologic material has not been significantly affected by pedogenesis.

Spodosol formation is inhibited if base-rich litter is available to the soil, permitting organic matter to accumulate. Most deciduous hardwood trees, particularly sugar maple, supply abundant fertile litter to the forest floor. Substantial amounts of silt and clay, if present in the soil profile, allow retention of nutrients within reach of plant roots and soil organisms. The soil which forms under these conditions is called an Alfisol (Gray-Brown Podzolic). The vertical profile differs from that of a Spodosol in that the B2 or illuvial horizon (called an argillic horizon) is largely a zone of clay accumulation rather than of iron and organic material. Also characteristic of Alfisols is a dark surface horizon rich in organic matter, 7-16 cm (3-6 in) thick, overlying the grey leached horizon.

In the Apostle Islands, conditions promote development of Spodosols in some areas and Alfisols in others. Where glacial or lacustrine fine-grained material is at or near the surface, Alfisols have formed. The initial material was somewhat calcareous and the clays have retarded leaching of the calcium and other cations. Where surface drainage is good these soils are termed Typic Eutroboralfs (Hibbing and Ontonagon series) (Fig. 3a). Where drainage is somewhat poor these soils are termed Aquic Eutroboralfs (Rudyard and Selkirk series). Eutroboralfs are fertile northern Alfisols and are extensive on four of the five mapped Apostle Islands.

Sand mixed with gravel occurs in deposits which may exceed 1 m in thickness. These materials have experienced long-continued podzolization and typically have formed Spodosols. On steep slopes, where much water runs off, the development of soil horizons has been retarded, giving the soils a young appearance. In other areas, the spodic horizon and podzolic profile are well formed. These two kinds of soils are classified as Entic (young) and Typic Haplorthods (Bibon, Vilas, Rubicon, Rousseau, and Karlin series). Moderately well drained soils in the catena are included in the Typic Haplorthods (Croswell and Orienta series) (Fig. 3b), but somewhat poorly drained members are Typic Haplaquods (AuGres series). Extremely gravelly deposits associated with ancient beaches have also given rise to Typic Haplorthods (Pence, Waiska, and Allouez

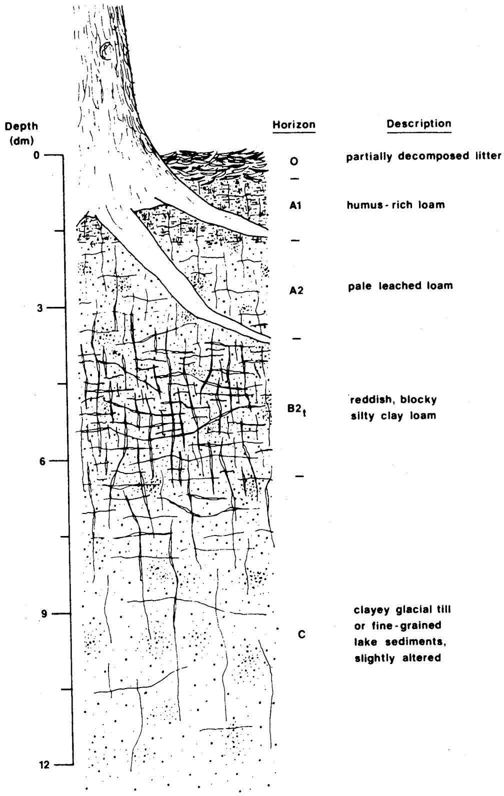

Fig. 3a. Schematic diagram of a Typic Eutroboralf on the Apostle Islands. The soil is well-drained, fertile, and characteristic of northern deciduous forests.

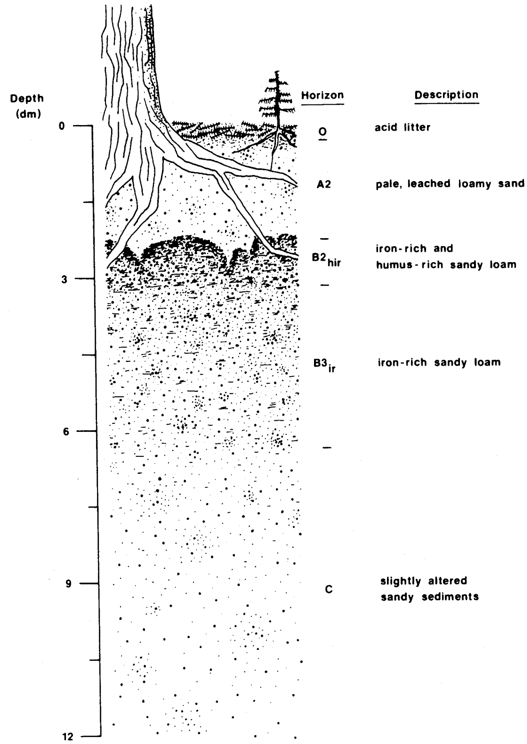

Fig. 3b. Schematic diagram of a Typic Haplorthod on the Apostle Islands. The soil is sandy, well-drained, infertile, and characteristic of coniferous forests.

series) (Fig. 3c). Typic Haplorthods represent the central concept of the Spodosol soil order.

In many areas, coarse materials overlying the glacial and lacustrine clays are of only moderate thickness (.3-1 m). There soil formation can be complex. The usual sequence of events includes leaching and formation of a spodic horizon in the coarse upper layer followed by leaching and clay concentration at and below the clay contact. The appearance is that of a Spodosol formed on top of an Alfisol (Fig. 3d). Such soils are termed "bisequal" (Hole, 1976). Bisequal soils are one form of intergradation between Spodosols and Alfisols; appropriately they are called Alfic Haplorthods (Superior, Dryburg, and Manistee series) when well drained, and Aqualfic Haplorthods (Allendale and Dafter series) when somewhat poorly drained.

In scattered depressions drainage is so poor that pedogenic processes have done little in 10,000 years but add organic material. These youthful soils are placed in the Inceptisol order and are called Mollic Haplaquepts (Munuscong series) because of the thick organic-rich surface horizon similar to that of Mollisols formed under prairie vegetation.

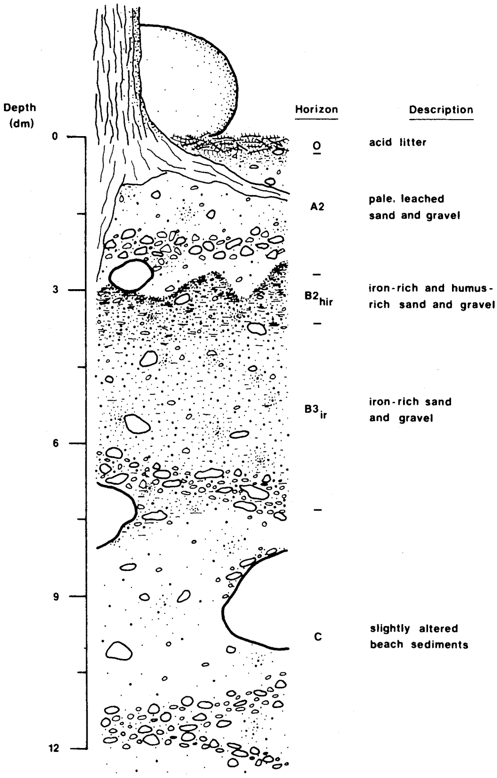

Fig. 3c. Schematic diagram of a Typic Haplorthod formed in gravelly beach deposits on the Apostle Islands.

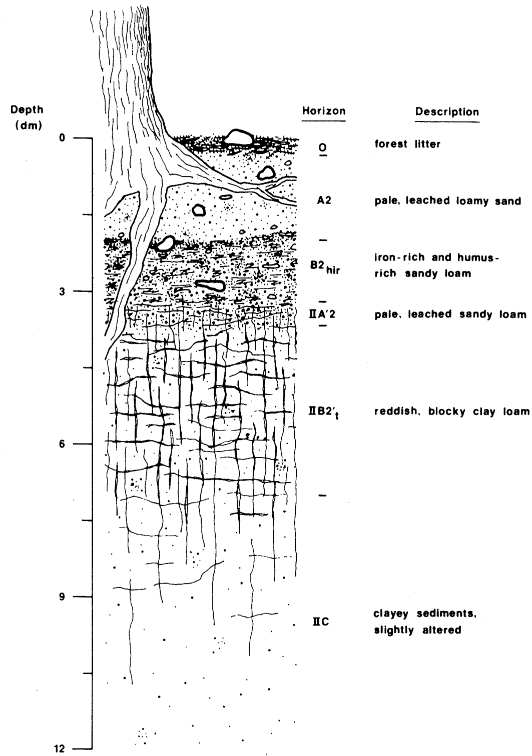

Fig. 3d. Schematic diagram of an Alfic Haplorthod formed in surficial beach sediments and underlying clayey sediments on the Apostle Islands. The soil is well-drained and has characteristics of both Alfisols and Spodosols.

Since soils are three-dimensional bodies (Buol, Hole, and McCracken, 1973) study of horizontal soil variability is important. The soil maps of Raspberry, York, Rocky, and Oak Islands (Figs. 4, 5, 6, 7) show major soil bodies. The soil pattern is more complex than can be mapped at the scales indicated. Not shown are inclusions of smaller soil bodies and the gradual and interfingering nature of lateral boundaries for which a drawn line is a gross simplification. Also designated for each soil body is the approximate land surface slope. Level land is placed in slope category *a* (0-2%), while land inclined at 20-30% is placed in slope category *e*. The steepest land, with slopes greater than 30%, usually occurs in association with bluffs or ravine systems, shown as land types.

The physiographic uniqueness of Oak Island is evident in the slope designations. Oak Island has a large part of its land surface in moderate slopes in contrast to York, Rocky, Raspberry, and most other Apostle Islands, which are chiefly level (0-2%) and gently sloping (2-6%) land (Fig. 8).

The soil maps reveal that Oak Island is also pedologically distinct. The soilscapes of the three smaller islands are dominated by Eutroboralfs and Alfic Haplorthods—soils

TABLE 1. Legend for figures 4, 5, 6 and 7.

Eutroboralfs	*Haplorthods*	*Miscellaneous Land Types*
A Typic Eutroboralf (Ontonagon, Hibbing)	G Typic Haplorthod (Bibon)	V Shallow to bedrock
B Aquic Eutroboralf (Rudyard, Selkirk)	H Aquic Haplorthod (Orienta)	W lake sand
Haplorthods	I Typic (Entic) Haplorthod (Vilas, Rubicon)	X organic material
C Alfic Haplorthod (Superior)	J Typic (Entic) Haplorthod (Croswell)	Y ravine complex
D Alfic Haplorthod (Manistee, Dryburg)	L Typic Haplorthod (Rousseau, Karlin)	Z bluff
E Aqualfic Haplorthod (Allendale, Dafter)	M Typic Haplorthod (Waiska, Pence, Allouez)	*Slope Classes*
Haplaquepts	*Haplaquods*	a 0-2%
F Mollic Haplaquept (Munuscong)	K Typic Haplaquod (AuGres)	b 2-6%
		c 6-12%
		d 12-20%
		e 20-30%

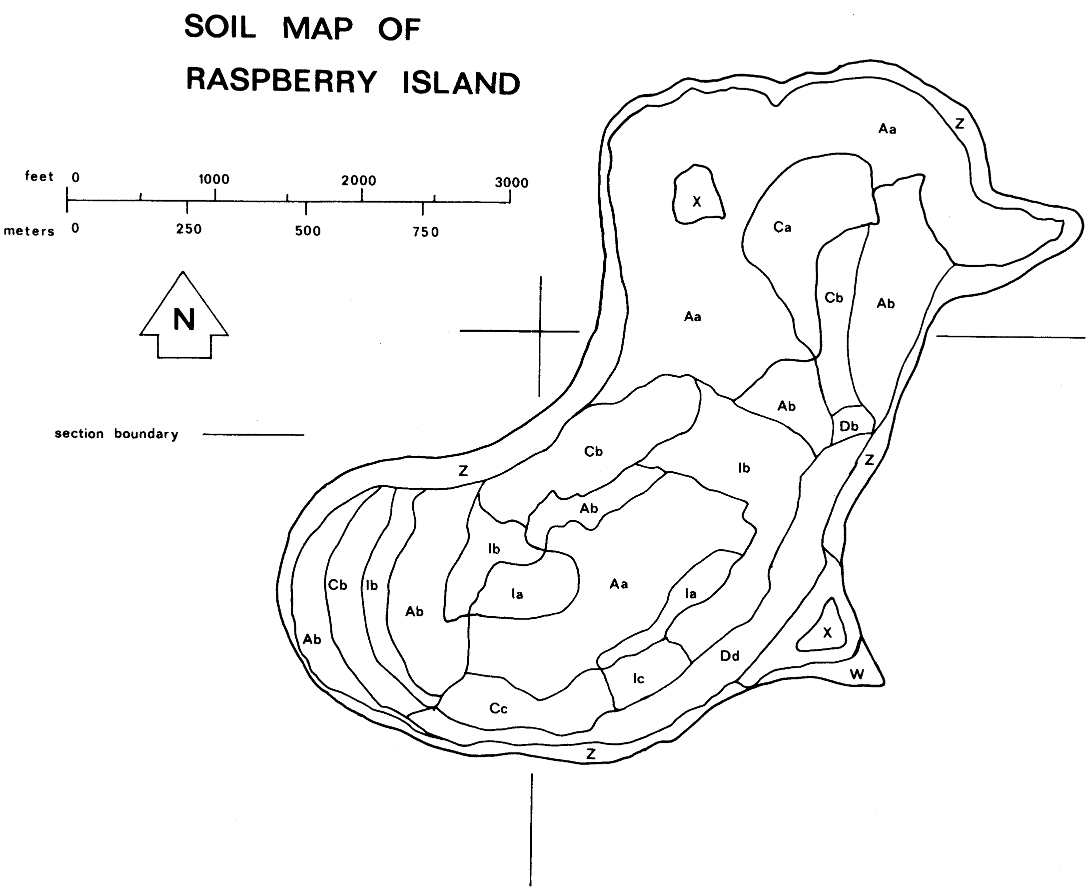

Fig. 4. Soil map of Raspberry Island.

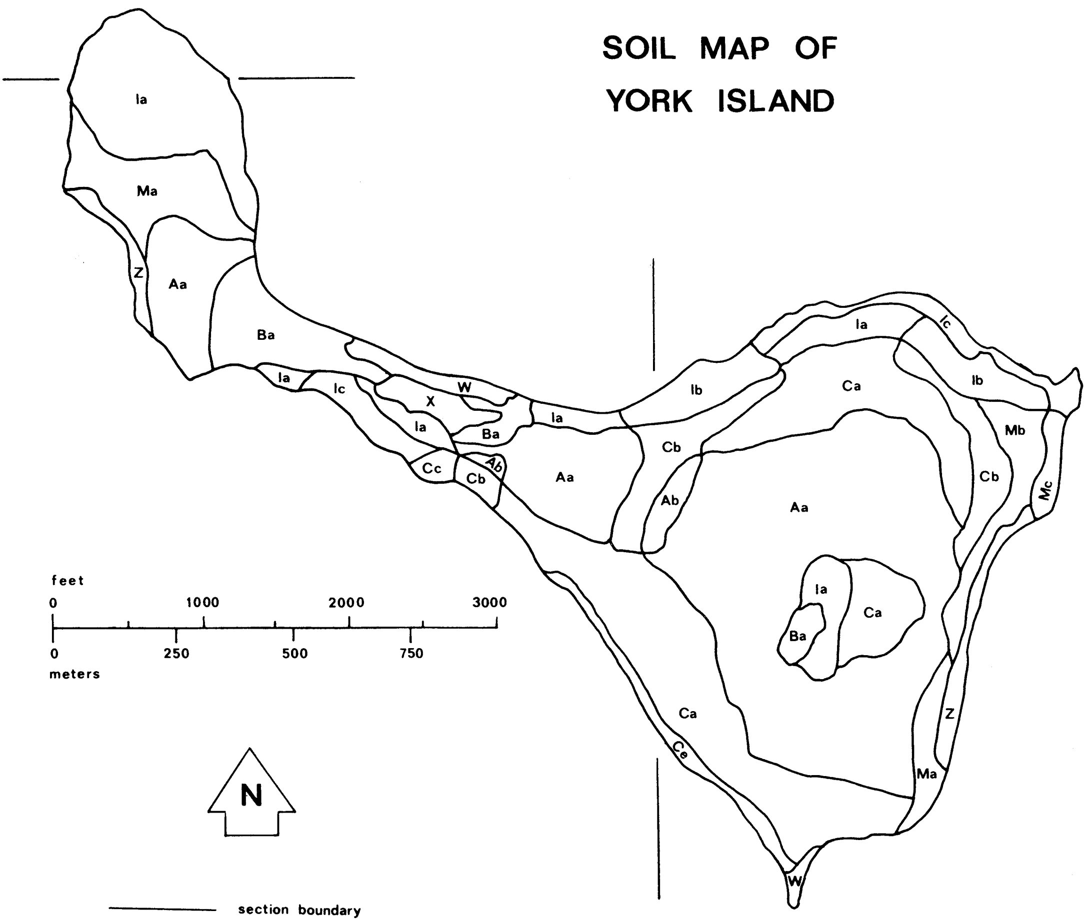

Fig. 5. Soil map of York Island.

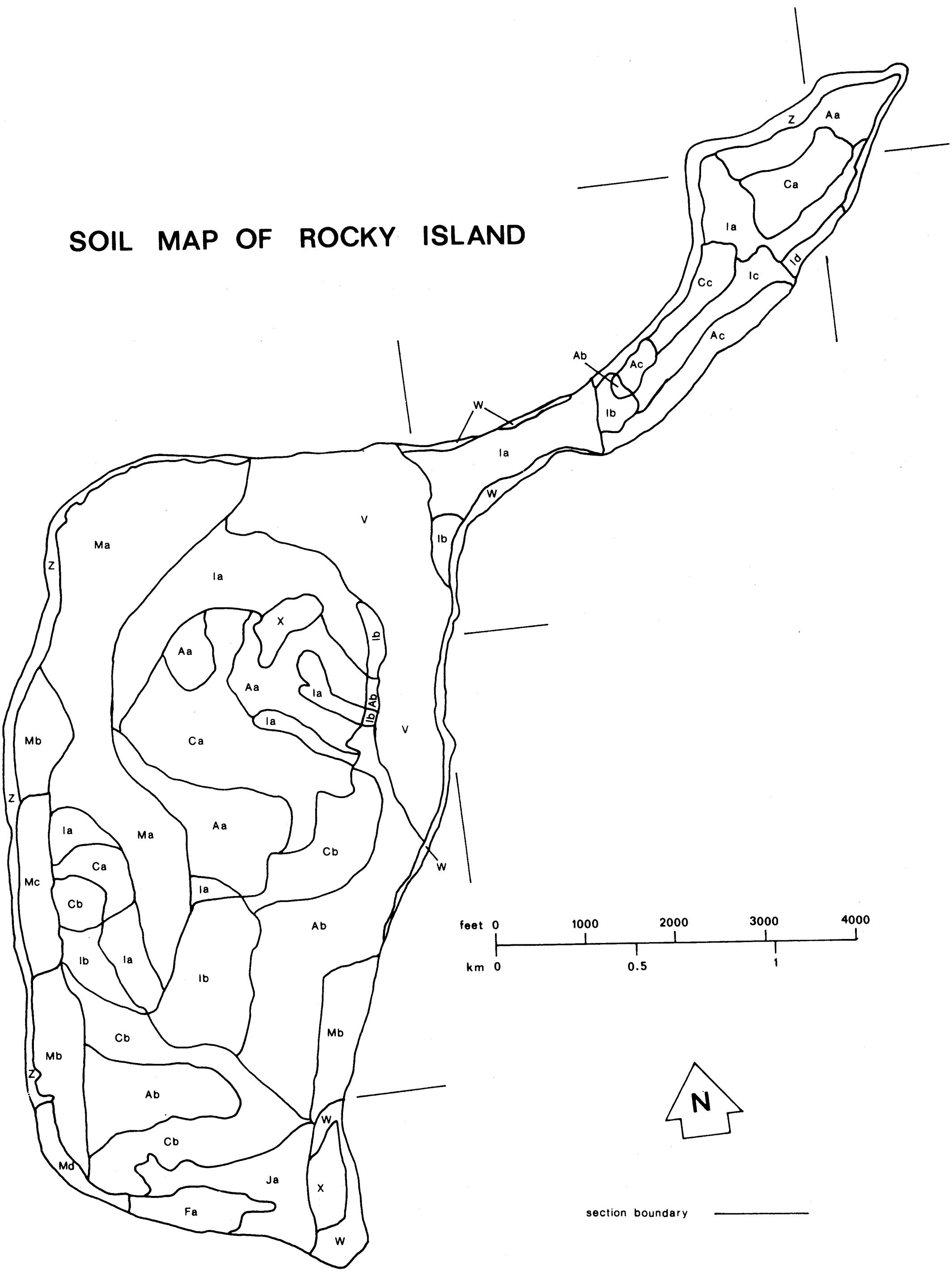

Fig. 6. Soil map of Rocky Island.

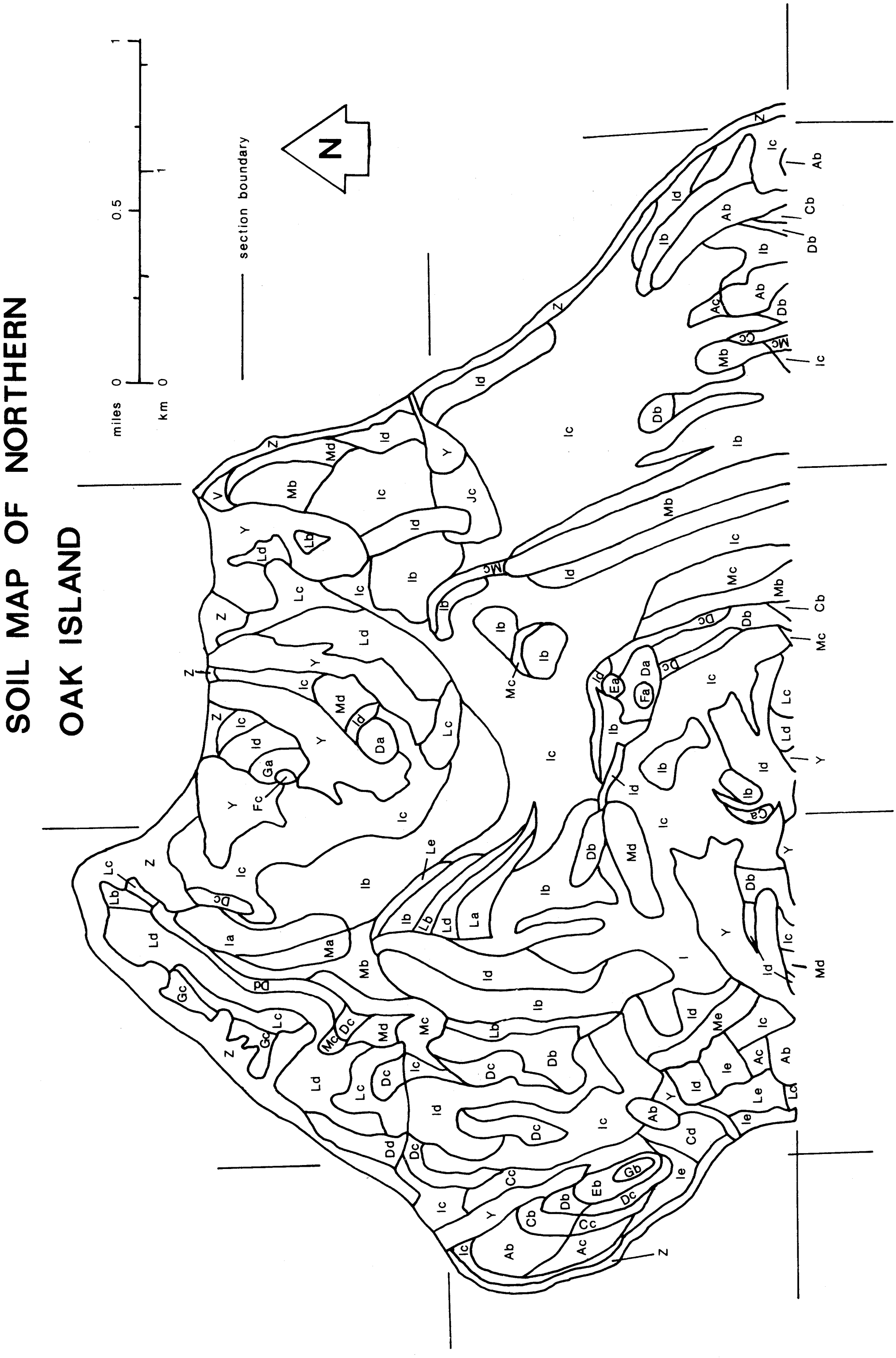

Fig. 7a. Soil map of northern Oak Island.

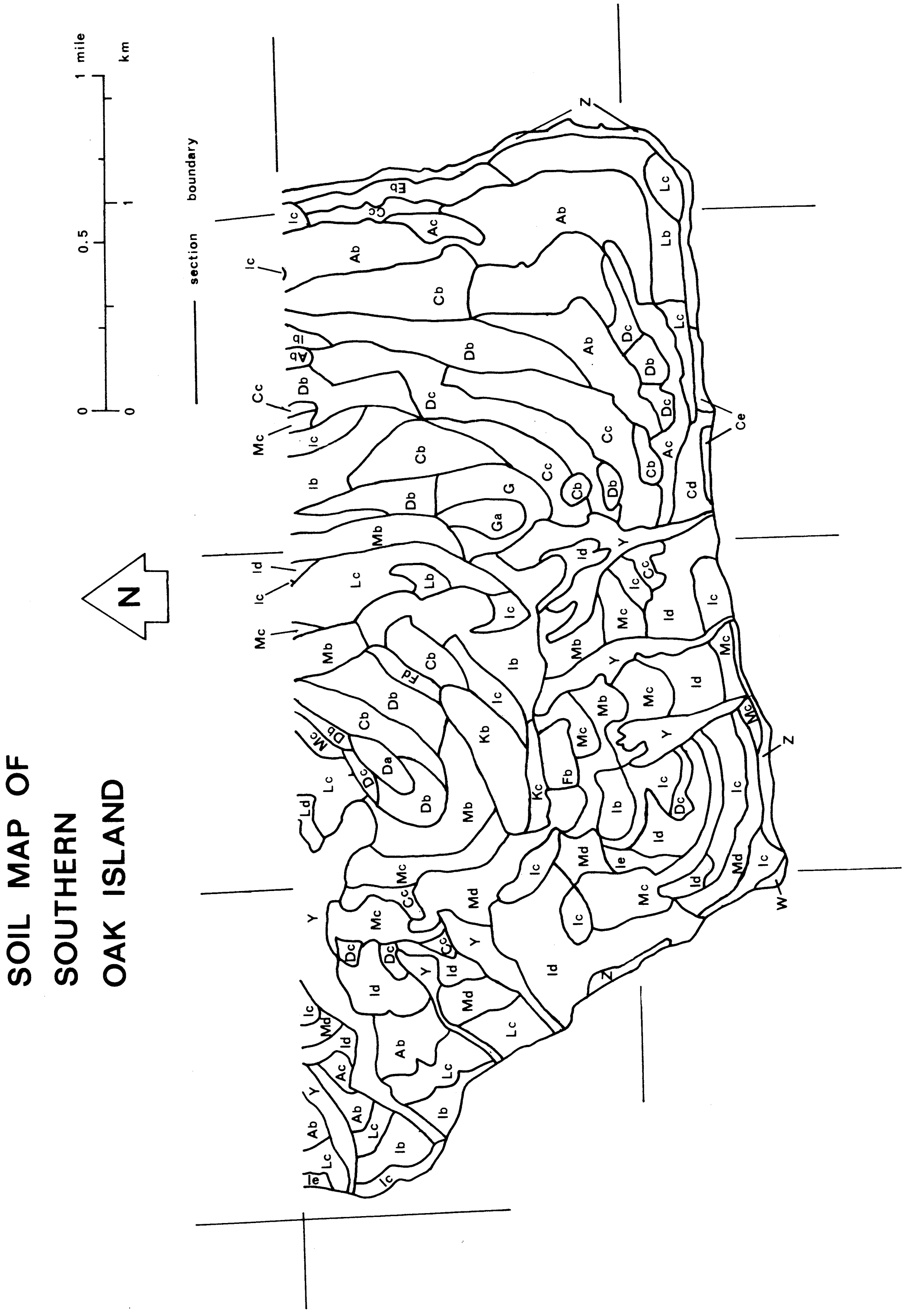

Fig. 7b. Soil map of southern Oak Island.

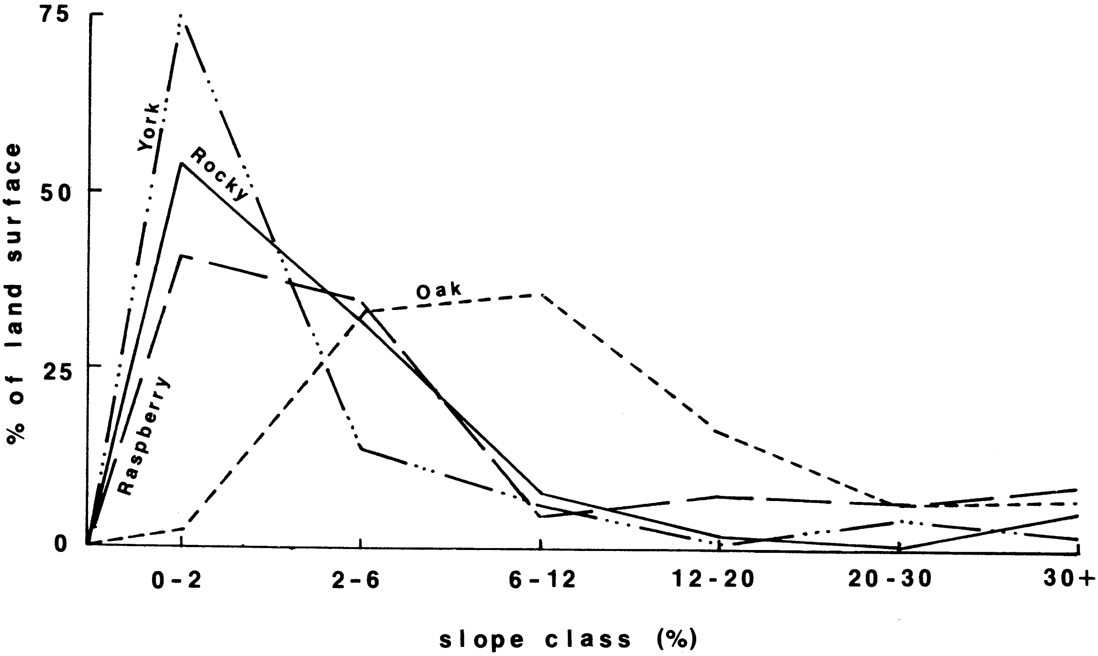

Fig. 8. Proportion of land area on Raspberry, Rocky, York and Oak islands in different slope classes.

formed in less than 1 m of coarse sandy material overlying glacial or glaciolacustrine clayey material. The coarse surficial layer, deposited by beach processes at times of higher water levels, is generally thin (less than 1 m) on these islands. On the other hand, more than 75% of the surface of Oak Island is covered with Typic Haplorthods or less well drained Spodosols, which typically form in thick (more than 1 m) deposits of coarse-grained materials. In only a few locations on Oak Island does the basal clayey sediment lie close enough to the surface for soil formation. However, the clayey substrate can significantly affect pedogenesis even if it is buried by more than 1 m of coarse beach deposits. Indirect evidence of subsurface clayey material, in the form of mottling was often present in profiles which were of loamy or sandy texture throughout their upper 1.5 m (5 ft). Oak Island soils are sandy and sloping, while the soils of Raspberry, Rocky, and York Islands are generally fine-textured and fairly level.

More detailed analysis suggests that sandy soils are associated with sloping land while clayey soils are associated with level land (Table 2). Observation points were selected by randomly overlaying grids (adjusted for differences of scale) on the soil maps; observations were recorded at each grid point.

If no relationship existed between thickness of coarse surface deposits and land surface slope, the observation frequencies should resemble those of Table 3. A contingency table analysis was performed to test for a possible relationship. The Chi Square statistic (χ^2) was calculated according to the formula

$$\chi^2 = \Sigma f_o^2/f_e - N$$

where f_o is the observed frequency at a given position in the table, f_e is the expected frequency assuming no relationship between the variables, and N is the total number of observations (252) (Blalock, 1972). The calculated chi square value was 62.6, highly

TABLE 2. Frequencies (%) for given combinations of land surface slope and surficial sand thickness, includes all points on Rocky, Oak, York and Raspberry Islands.

Slope angle (%)	Thickness of coarse surface layer (cm.) 0-25	25-100	100+	total
0-2	27	17	14	58
2-6	23	25	37	85
6-12	5	15	55	75
12-30	0	3	31	34
total	55	60	137	252

TABLE 3. Frequencies (%) at which points on all four islands would be expected to possess the specified combinations of land surface slope and surficial sand thickness, if the two properties are not related.

Slope angle (%)	Thickness of coarse surface layer (cm.) 0-25	25-100	100+	total
0-2	13	14	31	58
2-6	19	20	46	85
6-12	16	18	41	75
12-30	7	8	19	34
total	55	60	137	252

significant at a probability level of 0.001. There is less than one chance in a thousand that the positive association between land surface slope and coarse surficial material thickness results from chance.

The most probable explanation for the observed correlation between land surface slope and thickness of the coarse surficial material relates to the beach processes which deposited the sandy, gravelly sediment 8,000 to 11,000 years ago. Thick layers of coarse sediments can accumulate in the littoral (beach) zone only if three conditions are more or less satisfied:

1) a sediment surplus must exist; incoming material from erosion or longshore transport must exceed outgoing material;
2) a suitable depositional zone must be present; in excessively steep areas the suitable zone is very narrow; on broad, level beaches wave action causes the sand deposits to be extensive but thin;
3) sufficient time must be available; for sedimentation to build thick deposits, i.e. lake level must remain constant for a period.

The degree to which these three conditions were met differs between the islands, thus there are differences in the thickness of coarse beach sediments.

Although longshore drift has created a few small spits and forelands at former and present lake levels (Engstrom, 1972), the major source of sediment for beaches on all of the islands has been bluff erosion. Bluff erosion is favored by the presence of steep slopes above the beach level. When a relatively steep face is present, sediment is eroded from the face through undercutting by wave and ice action, followed by slumping, through sheet and rill erosion on the bluff face, and through gravity-induced slope processes. Sorting by wave action at the beach may remove the fine fraction of the bluff material, leaving coarser beach deposits, including boulders.

If conditions are favorable for bluff erosion, sediment surplus at the beach will lead to the accumulation of thick beach deposits. During emergence of the Apostle Islands these conditions were met on Oak Island, an island with great vertical relief and relatively steeply sloping flanks. There bluff erosion has contributed large amounts of sediment to beaches at all lake levels throughout the post-glacial period. On York, Rocky, and Raspberry Islands a large proportion of the land surface is in gentle and flat slopes, with no steep land above these surfaces to contribute sediment. Wave action on the relatively flat tops of these islands probably sorted and reworked the original surfaces, but the supply of new beach material was small.

Slope of the island surface at beach level determines the zone available for deposition of beach sediment. Thick accumulations of material are favored by moderate slopes. When the littoral zone is fairly level expenditure of wave energy over a wide area discourages thick sand accumulation by spreading the material laterally. On flat-topped islands like Raspberry, York, and Rocky, the wide littoral zone has a thin layer of beach deposits spread over the fine-textured material from the original surface. On an island with moderately steep slopes, such as Oak Island, the width of the littoral zone is limited, and sand accumulation is thicker. On a very steep original slope, a shelf-like littoral zone, with relatively thick sediment accumulation, may be constructed by wave action if ample time and surplus sediment are available. Some of the flatter slopes on the west side of Oak Island may be beaches built onto or cut into the original steep face.

Although the lake level fell rapidly, the unconsolidated glacial debris mantling the islands and the relatively high wave energy of Lake Superior allowed beaches to build rapidly. An island with moderately sloping sides always had sand accumulating as long as island emergence continued. The flat-topped, steep-sided islands were less likely to receive similar accumulations. Regardless of the elevation at which lake level temporarily stabilized, thick sand accumulations were unlikely; either there was a paucity of coarse sediment or there was an unfavorable depositional zone. Moderate slopes (approximately 5-20%) thus seem to be important in the accumulation of thick sand deposits. Differences in initial soil material between islands can be partially explained by this phenomenon.

The above discussion is important from a practical, as well as a theoretical, view. Recreational development of the Apostle Islands is proceeding under the direction of the U. S. National Park Service. Assessment of soil resources and evaluation of soil limitations for various recreational activities is essential for planning. Drainage is an important soil property and poor drainage presents serious problems for septic tank disposal fields or for more primitive waste disposal methods, as well as for paths, trails, and campgrounds. Poor drainage is most often encountered on level, fine-textured soils. Steep, sandy soils may present a serious problem because of the great erosion potential. The apparent correlation between surface slope and thickness of coarse surficial material suggests that most areas will have one problem or the other. Level land with loamy or sandy soil has few limitations but is not common on the mapped islands. It does not seem likely that other islands in the archipelago will have soils more suited to recreational uses, because all the islands were subject to the same beach processes. The biologic and pedologic environments of the Apostle Islands are fragile and development will demand great care.

Conclusion

This paper presents the findings of two field seasons work in the Apostle Islands. The prevalent soils on the four islands studied are of two basic kinds: fertile Alfisols, formed in deposits of fine-grained glaciolacustrine material (Eutroboralfs), and sandy Spodosols developed in coarse beach deposits (Haplorthods). The Apostle Islands possess a landscape with widely varying characteristics of initial material and topography, and which, in conjunction with the cool, humid continental climate, allow a variety of biotic communities to thrive. The coexistence in this region of Alfisols, usually found in more southerly locations under deciduous forest, and Spodosols, typically found in more northerly climatic zones with evergreen vegetation, attests to the diversity and complexity of the pedogenic environment.

Development of soil maps for the four islands surveyed allows analysis of the spatial variability of soils. Reconnaissance soil surveys completed 10 or more years ago (Ableiter, and Hole, 1961; Hole, *et al.*, 1968) show virtually all the Apostle Islands as having soils formed in thin coarse deposits overlying basal clayey material (Eutroboralfs, Alfic Haplorthods). This portrayal is accurate for York, Rocky, and Raspberry Islands, but not for Oak Island. Oak Island is dominated by thick surficial sand and gravel deposits and the Typic and less well drained Haplorthods formed in them. The preponderance of sandy soils on Oak Island is explained by the correlation between thick coarse deposits and steep land surface slope.

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THE CADDISFLIES (TRICHOPTERA) OF PARFREY'S GLEN CREEK, WISCONSIN[1]

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Abstract

Life cycles, biology and ecology of 17 species of Trichoptera in Parfrey's Glen Creek are reported. *Wormaldia moestus* and *Oligostomis ocelligera,* rare in Wisconsin, were found. Other species such as *Diplectrona modesta, Parapsyche apicalis, Rhyacophila vibox,* and *Dolophilodes distinctus,* which seldom occur commonly in any stream, were a significant part of the fauna. Closely related species were often segregated temporally or spatially. *Limnephilus rossi* is reported from Wisconsin for the first time and its larva is described.

Parfrey's Glen Scientific Area in Sauk County, Wisconsin has a unique flora and fauna that has received much attention (Vorhies, 1909; Hilsenhoff, 1974; Webb, 1974; Wynn and Loucks, 1975). Flowing southward through the area is Parfrey's Glen Creek, a small, permanent, spring-fed stream. Its insect fauna differs significantly from most other streams in southern Wisconsin, and is dominated by an unusual assortment of caddisfly larvae (Trichoptera). It also has significant populations of the stoneflies *Isoperla clio* (Newman), *Allocapnia nivicola* (Fitch), *A. rickeri* (Frison), *Amphinemura delosa* (Ricker), and *A. linda* (Ricker), the mayfly *Baetis vagans* (McDunnough), the beetles *Optioservus fastiditus* (LeConte), *Helichus striatus* (LeConte), *Agabus seriatus* (Say), *A. confusus* (Blatchley), and *Hydrobius melaenus* (Germar), and several unidentified Diptera. Because of increased public use of this area (Wynn and Loucks, 1975), a study was begun in 1975 to document the unique caddisfly fauna and to learn more about their biology and ecology.

[1] Research supported by the College of Agricultural and Life Sciences, University of Wisconsin-Madison and carried out in cooperation with the Wisconsin Department of Natural Resources.

Parfrey's Glen Creek is characterized by series of riffles, rapids, small waterfalls, and occasional pools. In winter it is frozen, and in summer most of it is densely shaded by vegetation, and in the gorge by cliffs. Only a few patches of aquatic mosses are present, mostly outside of the gorge. The average flow is 21 l/sec and varies little seasonally, with currents mostly 15 to 45 cm/sec and depths of 1 to 40 cm. Temperatures vary from 0 to 18°C, the maximum occurring in early spring before the trees are in leaf. After the stream is shaded, temperatures remain fairly constant at 16.5°C throughout the summer. Except for some siltation due to visitor use, the stream is free of pollution with oxygen at or near saturation level. The stream has a gradient of 1.92 hm/km, a pH of 7.8, total alkalinity of 216 mg/l, and a specific conductance of 528 μmhos/cm.

METHODS

To collect caddisflies for determination of life cycles, a D-frame aquatic net with a 1.0 mm mesh was held against the stream bottom and the substrate immediately upstream was thoroughly disturbed (using one's feet) for approximately one minute to dislodge insects. Insects and debris collected in the net were placed in a white plastic pan with a little water. Caddisflies were removed from large pieces of debris, water, and the net and preserved in 70% ethanol. The remaining debris was preserved for more thorough examination in the laboratory. Large rocks or logs that could not be sampled by this method were lifted from the water and caddisflies were scraped into the net or directly into collecting jars. Prior to disturbing the substrate to dislodge larvae, and with the D-frame net in position, substrate materials were removed from the water and examined for pupae. All possible microhabitats were sampled semimonthly from March 19, 1975 to November 6, 1975; six or seven sites were sampled on each date.

To determine microdistribution, sampling sites were selected to be as homogeneous as possible with respect to current, substrate type, and water depth. Current was measured with a pigmy current meter 2.5 cm above the substrate and water depth was calculated as the average of measurements taken at the corners and center of a sampling site. Stones were measured after sampling to determine the greatest diameter. Substrate units sampled were silt, detritus, leaves, moss, sand (1 mm to 2 mm), gravel (3mm to 2 cm) and stones 2-5 cm, 5-10 cm, or >10 cm). An average of 45 samples were collected each spring (April-June), summer (July-September), autumn (October-December), and winter (January-March).

Flight periods were determined from adult collections and laboratory reared insects. Daytime collections were made by sweeping riparian vegetation and by picking adults from tree trunks near the stream or exposed rocks in and along the stream; at night, adults were collected in light traps. In the laboratory, adults were reared from pupae, prepupae or mature larvae in aerated water maintained within 2°C of the stream temperature.

Life cycles were determined by analyzing larval growth rates and the presence of prepupae, pupae, and adults. Each larval instar was determined by head capsule width measured with an ocular micrometer.

Larvae were identified using keys by Ross (1944), Flint (1960, 1961, 1962), and Hilsenhoff (1975). *Lepidostoma* larvae were identified using the metamorphotype method of Milne (1938). Adults were identified using keys and illustration by Betten (1934, 1950), Ross (1944, 1946), and Leonard and Leonard (1949a). Specimens were also compared with identified adults in the University of Wisconsin Insect Collection, and voucher specimens were deposited in this collection. The reported distribution in Wisconsin is based on Longridge and Hilsenhoff (1973), and specimens in the University of Wisconsin Insect Collection.

Seventeen species of caddisflies were collected from Parfrey's Glen Creek; these are the only species known to occur in this stream. Life cycles and numbers collected of the fourteen most common species are summarized (Table 1) and notes on the biology and ecology of all species follow.

Caddisfly Biology and Ecology

Dolophilodes distinctus (Walker) 1852

Dolophilodes distinctus has been found in rapid, cool streams in northern Wisconsin and a few streams in Sauk County. It was relatively common in Parfrey's Glen Creek. Adults were captured every month except September and October, and other workers have noted adults present over much or all of the year (Longridge and Hilsenhoff, 1973; Ellis, 1962; and Leonard and Leonard, 1949b). The population in Parfrey's Glen Creek is bivoltine with peaks of emergence in March-April and July-August. Tebo and Hassler (1961) also noted two peaks of emergence in this species, in April and in September.

Brachypterous females were collected from late February to the first week of April. They were found crawling on the stream bank, under rocks and logs near

TABLE 1. Development of 14 species of Trichoptera in Parfrey's Glen Creek indicating life stages[1]

Species	No. of larvae	Month Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.
Dolophilodes distinctus	451	P,A	P,A	3 P,A	2,3 4 A	3 4,5 A	4,5 P,A	2 5 A	3 4,5 PP	4,5 PP	5 PP,P,A
Diplectrona modesta	4,255	3 4,5	3 4,5	3 4,5 PP,A	3 4,5 PP,A	2 4,5 A	1,2 5	2,3 5	3 4,5	4,5	3 4,5
Parapsyche apicalis	795	5	5	4,5 PP,P,A	4,5 PP,P,A	5 A	1,2,3	2,3	3 4	4,5	4,5
Hydropsyche slossonae	2,418	2	2 5	2,3 5	2,3 4,5 PP,P,A	4,5 A	5 A	2 5 P,A	1,2,3 5 PP,A	1,2,3 5	2 5
Rhyacophila vibox	1,838	4,5	5	2,3 5	5 PP,P,A	2 P,A	1,3	1,2,3 4	2,3 4	4,5	4,5
Glossosoma intermedium	16,129	3 4	3 4	3 4,5 PP,P,A	4,5 A	4,5 PP,P	3 4,5 PP,P,A	1,2 A	1,2 A	2,3 A	3 4
Brachycentrus occidentalis	58	4,5		P,A			2	3	3 4,5	4,5	4,5
Pycnopsyche guttifer	118	4,5	5	4,5	5	5			A	3 A	2,3 4 A
Hesperophylax designatus	27	5		P	P,A		2,3 4 A	2,3 4	4	5	5
Limnephilus rossi	304	2		2,3 4	3 4,5	2 5	4,5	3 4,5	5 PP	4 P	3
Neophylax concinnus	1,731	2 3,4	2 3,4	2,3 4,5	3 4,5	5 PP	3 PP	PP,P	A	A	1,2,3 A
Lepidostoma bryanti	296	4,5	5	4,5 A	5 P,A	1,3 A	2,3	2,3	3	4	4,5
Lepidostoma costalis	893	2	2	2,3	2,3 4	3 4,5	5 PP	P,A	3 A	3	2,3
Lepidostoma griseum	939	2	2	2,3	2,3 4	4,5	5	5 PP,P,A	P,A	2 P	1,2,3

[1] Life stage noted only if it constituted 10% or greater of the months sample of that species. 1,2,3,4,5 = Larval Instar; PP = prepupae; P = Pupae; A = Adult.

the stream, and on exposed rocks in the stream. Ross (1944) also found only wingless females in winter and noted that winter males were winged and tended to be larger than in other seasons. In warmer months, adults were found on tree trunks close to the stream and under rocks and logs along the stream.

Larvae that hatched from eggs laid in March and April grew very rapidly and by the end of June nearly 90% were in the fifth instar. Pupae were first noticed in early July. Early instar larvae from the July-August emergents were first noticed in mid-August. They grew rapidly and by November all were in the fifth instar. The winter was spent mainly as pupae, but prepupae and fifth instar larvae were also present. By late February more than 80% were in the pupal stage. Throughout the winter a small number of adults emerged to produce the brachypterous phenotype. The presence of some adults quite removed from periods of peak emergence may be attributable to a long adult life span.

Larvae inhabited a wide range of substrates, currents and water depths. They were found in currents ranging from 5 cm/sec to 97 cm/sec, mostly on the under surface of rocks 12 cm or larger. Depths greater than 15 cm were preferred, but larvae were not uncommon in water as shallow as 5 cm.

Pupal chambers were fastened to the under surface of stones, usually 10 cm or larger. Pupae were found in currents of 19 to 70 cm/sec at depths of 4 cm to 20 cm and preferred currents faster than 30 cm/sec.

Wormaldia moestus (Banks) 1914a

Wormaldia moestus is rare in Wisconsin. Besides Parfrey's Glen Creek and one other Sauk County stream, it has been collected only in the northeastern counties. Eight larvae were found, all of them in the densely shaded stream gorge, mostly on the under sides of rocks 10 cm or larger, in currents of 23 to 70 cm/sec and water 10 to 16 cm deep. The two smallest larvae were collected in early and late April (head capsule widths 0.35 and 0.50 mm respectively). Those collected in June, November, and February had head capsule widths of 1.70-1.80 mm. Larvae apparently grow rapidly in spring and spend summer, autumn and winter in the terminal instar. Pupation probably occurs in late winter with emergence in early spring. Ross (1944) collected adults in Illinois during the first week of March.

Diplectrona modesta (Banks) 1908b

Diplectrona modesta frequents rapid clear brooks and streams throughout Wisconsin. In Michigan Leonard and Leonard (1949b) found it only in tiny, spring-fed brooks. Parfrey's Glen Creek is one of the few streams in Wisconsin where it comprises a significant part of the caddisfly fauna, and here it was the dominant hydropsychid. *Diplectrona modesta* was univoltine with adults present from early May to July, and peak emergence the last week of May and first week of June. Adults were found resting on tree trunks.

A wide range of instars was often present, indicating an extended hatching period. Larvae grew steadily over the summer and by mid-August more than 80% were in the fourth and fifth instar. The larvae developed little during the winter, with growth resuming in early spring. Prepupae were found from April 29 to July 9, pupae from June 12 to July 24.

First and second instar larvae preferred 2-5 cm stones in currents of 13 to 29 cm/sec; depth was not important. They were mostly on the undersurface, but were found on other faces if vegetation was present. Later instars were less selective and inhabited all sizes of stones and occasionally vegetation in currents of 12 to 68 cm/sec, but preferred currents of 15 to 36 cm/sec. Mostly on the undersurfaces of stones, they inhabited other faces if fissures or protuberances protected them from the current. In late spring, fifth instar larvae preferred deeper water (>12 cm), larger stones (>10 cm) and slower currents (<46 cm/sec) than in other seasons, probably as a result of movement to pupal habitat in spring. Pupae attached chiefly to the undersurface of rocks greater than 10 cm in water deeper than 11 cm with currents of 15 to 44 cm/sec.

Parapsyche apicalis (Banks) 1908b

In Wisconsin *Parapsyche apicalis* occurs in small, cold, rapid streams, mostly in the north. It was not common in Parfrey's Glen Creek. Adults of this univoltine species were present from April 30 to June 12 with the emergence peak the last two weeks of May. Longridge and Hilsenhoff (1973) and Leonard and Leonard (1949b) collected adults into summer and early autumn.

First instar larvae were collected first on July 9 indicating an incubation period of 3-4 weeks. The larvae grew slowly in July and August and more rapidly in September so that by the end of September almost 80% were in the fourth instar. Winter was spent mainly as fifth instar larvae, but second, third and fourth instars were also present. Prepupae and pupae were present from April 29 to May 12.

Developmental stage and season influenced larval distribution. First and second instar larvae clearly preferred vegetation in currents of 30 to 78 cm/sec and depths less than 12 cm. In autumn, third and fourth instar larvae were most common on stones 5 cm or larger in currents of 23 to 53 cm/sec and depths greater than 6 cm. In winter, they also colonized vegetation growing on rocks. Fifth instar larvae were found at all depths and in autumn and winter were most common on rocks greater than 10 cm and in currents faster than 30 cm/sec. They occurred on the bottom of bare rocks, and on other faces if vegetation was present.

Approximately 60% of the pupal chambers were constructed of vegetation, the rest of sand grains. Flint (1961) noted that pupal cases were almost exclusively organic material and only rarely constructed of sand grains. Pupal cases of vegetation were found in vegetation and completely enclosed the pupa. Sand cases were found on the undersides of stones larger than 5 cm in diameter in currents less than 15 cm/sec and at depths greater than 6 cm.

Hydropsyche slossonae (Banks) 1905

Hydrosyche slossonae is widely distributed in clear, cool, swiftly flowing streams throughout Wisconsin, and was the second most common hydropsychid in Parfrey's Glen Creek. It is univoltine with a long flight period (Longridge and Hilsenhoff, 1973; Leonard and Leonard, 1949b; Ellis, 1962; and Ross, 1944). Adults were collected from May 19 to September 18. On August 28, 1975, 161 females and 5 males were caught in a light trap. While males may not be as strongly phototropic as females (Leonard and Leonard, 1949a), Schuhmacher (1970) found females to be generally more prevalent than males in the genus. Eggs were found in late August and September on the sides and beneath rocks and logs. They were roundish, off-white, and laid in one-layered patches of about 260 eggs.

Early instar larvae were first evident in early July. Most grew very slowly and overwintered in the second instar. Growth resumed in late March and by the end of April, 80% were in the third instar. Some larvae overwintered in the fifth instar and pupated in late spring, accounting for adults in May and June.

Segregation of instars was evident. First and second instar larvae were most common on vegetation while later instar larvae preferred bare stones 5-15 cm in diameter at depths less than 11 cm. Nets were spun in areas protected from the full force of the current. Fifth instar larvae were also found in vegetation on the upper surface of rocks in currents greater than 65 cm/sec. All larvae were most common in currents greater than 18 cm/sec.

Pupae were attached to vegetation or to the bottom of stones 5 cm or larger in diameter, usually in currents of 12 to 36 cm/sec. Depth did not significantly limit distribution, although pupae were not found at depths less than 4 cm unless the current was greater than 30 cm/sec.

The three hydropsychids, *H. slossonae, D. modesta* and *P. apicalis* were segregated temporally and spatially. *Hydropsyche slossonae* was temporarily isolated by growing in late spring while *D. modesta* and *P. apicalis* grew most actively in autumn. Early instars of *D. modesta* and *P. apicalis* were segregated spatially, with *P. apicalis* being found in vegetation on upper surfaces of rocks in fast moving shallow water and *D. modesta* mostly under bare stones over a wide range of depths and currents. Later instars were not segregated spatially, but mature larvae eat different foods (Shapas and Hilsenhoff, 1976).

Rhyacophila vibox (Milne) 1936

Rhyacophila vibox is found throughout Wisconsin in small, cold, spring-fed streams. Flint (1962) reported larvae only in springs and spring brooks less than two feet wide. It was a common univoltine species in Parfrey's Glen Creek. Adults were collected mostly from cracks or fissures of tree bark. They were found May 22 to June 20 corroborating published flight periods (Longridge and Hilsenhoff, 1973; Ross, 1944; Ellis, 1962). First instar larvae appeared in early July and grew slowly so that by mid-August more than 70% were still in the first and second instar. Growth accelerated in September, and by early November more than 70% were in the fifth instar. Winter was spent in the fourth or fifth instar and by March most were in the fifth instar. Prepupae were found April 20 to May 5 and pupae April 29 to June 12.

Life stages showed some segregation by microhabitat. First instar larvae were found only in currents less than 45 cm/sec, while later instars had no current limitations, except in spring and summer when they were most abundant in currents faster than 30 cm/sec. All larvae avoided pools. Vorhies (1909) reported *R. vibox* larvae in the moderately swift portions of Parfrey's Glen Creek. First instar larvae were limited to the lower surfaces of stones. Later instars also inhabited vegetation on the upper surfaces and sides of stones, but were most common under stones of 5-10 cm. During autumn, winter, and spring, larvae were also found in leaf mats, under the bark of submerged logs, and on large stones isolated in sandy stretches. Depth never restricted larval distribution.

Pupae were most common in currents greater than 25 cm/sec and depths greater than 10 cm. Stones greater than 3 cm in diameter were preferred as pupation sites, although some pupal chambers were attached to stones barely larger than the chamber.

Glossosoma intermedium (Klapalek) 1892

Glossosoma intermedium occurs in cool, woodland streams throughout Wisconsin, and was the most abundant caddisfly in Parfrey's Glen Creek. At some sites their cases almost covered the stream bottom. *Glossosoma intermedium* was univoltine with overlapping generations, the adults having two periods of emergence. From April 19 to June 1, less than 10% emerged, with peak emergence during the first half of May and a male: female ratio of 9:1. More than 90% emerged from July 7 to October 23, mostly during the last two weeks of July and first week of August. During this second emergence period the male:female ratio was 1:2. Adults were found resting on trees and riparian vegetation.

First instar larvae of the spring generation were noticed first in mid-June. They grew steadily and by the first week of November were in the fifth instar or prepupal stage in which they overwintered. By early April most individuals were prepupae, and pupae were found from the first week of April to the end of May. First instar larvae from the summer emergence were first collected July 24 and grew slowly over the autumn, overwintering as third and fourth instars. Growth accelerated in mid-April and by mid-June more than 70% were prepupae.

Larvae were found over a wide range of currents, substrate types, and water depths. There was some segregation of life stages, and seasonal differences in distribution were also evident. First and second instar larvae preferred currents less than 30 cm/sec and stones 3-7 cm. A few were found in gravel. Instars three to five were found in currents ranging from pools to 96 cm/sec, but most were in currents of 15 to 30 cm/sec. They inhabited a wide range of substrates, but were most common on stones 5 cm or larger. Larvae occurred only on the downstream side of rocks or other protected areas in currents greater than 30 cm/sec, but on all sides in slow currents. Larvae in pools were found only on stones or logs free of silt or detritus. In summer, fifth instar larvae even occurred on rocks and logs that protruded above the water's surface provided the surface was continually wetted.

Just prior to pupation the bottom strap of the case is cut away and the dome-shaped upper portion is cemented to a rock or other support (Ross, 1944). Most pupae were found in currents greater than 22 cm/sec, at depths greater than 12 cm, and on rocks larger than 10 cm in diameter. Pupae were also found on logs and smaller stones, though much less frequently. A few were found in pools. In currents greater than 30 cm/sec pupae occurred on surfaces protected from the full force of the current, while in slower currents pupae were present on all surfaces. Pupae occurred in aggregations, with some clusters containing more than one hundred individuals.

Oligostomis ocelligera (Walker) 1852

Oligostomis ocelligera is uncommon in Wisconsin and rare in Parfrey's Glen Creek; only two larvae were found during this study. Both had head capsule widths of 2.25 mm and were collected February 29, 1976, from detritus on the stream bottom at a depth of 10 cm in a current of 24 cm/sec. Lloyd (1921) stated that the larvae are bottom dwellers that crawl over the stream floor, or rest among the trash and litter. He reported pupation in mid- or late April in the stream bed or in dead wood; in New York emergence occurs during the last two weeks in May. Longridge and Hilsenhoff (1973) collected adults May 28 and June 4 in Wisconsin.

Brachycentrus occidentalis (Banks) 1911

Brachycentrus occidentalis occurs in cold streams in all but the southeastern corner of Wisconsin. Only 58 larvae were collected, and the species was regarded as uncommon in Parfrey's Glen Creek. Extensive notes on various aspects of its biology have been published recently by Gallepp (1974, 1976) and Gallepp and Hasler (1975). Adults were found in Parfrey's Glen Creek April 29.

Early instar larvae were noticed first in late July. They grew steadily and by the end of September almost all were in the fifth instar, the stage in which they overwintered. Gallepp and Hasler (1975) observed the same pattern of growth in Lawrence Creek, Wisconsin.

In summer, larvae were found on the upper surface of rocks in currents of 10 to 31 cm/sec and water less than 6 cm deep. Throughout the year larvae were found in open areas or lightly shaded sections of the stream. Gallepp (1976) also noted the preference of this species for areas exposed to bright sunlight. No pupae were collected.

Pycnopsyche guttifer (Walker) 1852

Pychnopsyche guttifer has been collected throughout Wisconsin. Adults of this uncommon, univoltine species were collected September 18 to November 6 from riparian vegetation. On November 6, when snow was present, they were found crawling on the stream banks.

Early instar larvae were noticed first in mid-October. They grew actively over the autumn and winter months so that by early March all were in the fifth instar. This was the only caddisfly in Parfrey's Glen Creek to grow rapidly during the winter, thus avoiding competition with most other herbivores and detritivores. Only fifth instar larvae were found in spring and early summer; no larvae were found in late summer. Cummins (1964) reports that during the summer larvae fasten their cases to sticks, aquatic vegetation, or cobbles, and remain inactive until pupating in early autumn. Neither pupae nor prepupae were found in this study.

Larvae were most abundant in pools or along the banks where they crawled over debris and leaves. Depth was not significant in determining distribution. A few individuals collected in the autumn were found on the bottom of loosely packed stones (5-10 cm in diameter) in currents up to 20 cm/sec. Cummins (1964) found that during low flow larvae moved into the middle of the stream if periphyton was abundant. Feldmeth (1970) found that *P. guttifer* larvae were swept off the substrate by currents greater than 15 cm/sec.

Early instar larvae constructed cases from leaf and stick matter, the leaf material predominating. As the larvae grew, the ratio was reversed and stick material dominated as described by Flint (1960).

Hesperphylax designatus (Walker) 1852

Hesperophylax designatus occurs throughout Wisconsin in small, cold streams. Only 27 larvae were found in Parfrey's Glen Creek. Adults of this univoltine species were collected May 22 to July 24 from riparian vegetation, with peak emergence in late May. In other Wisconsin studies Longridge and Hilsenhoff (1973) noted a flight period from April 27 to August 24, and Vorhies (1905) found adults March 15 with peak emergence in mid-April.

Early instar larvae were noticed first the last week of July. They grew steadily over the summer and autumn, and overwintered as fifth instar larvae. Prepupae were found the first week of April and pupae the last week of April and first week of May. Vorhies (1905) noticed that in mid-February most larvae had begun to prepare for pupation.

A seasonal difference in habitat selection was evident. In summer, larvae inhabited mostly logs and occasionally gravel and small stones (less than 5 cm). They were found only in currents slower than 20 cm/sec. In autumn and winter, larvae preferred the undersides of stones 5-10 cm in diameter or vegetation on these stones, and were found mostly in currents faster than 40 cm/sec. Water depth did not restrict distribution.

Detailed descriptions of cases are in Vorhies (1905, 1909) and Lloyd (1921). Pupae were found clustered on undersides of rocks greater than 10 cm in pools or in currents less than 15 cm/sec and depths greater than 20 cm. Clustering of pupae has been reported previously for this species (Vorhies, 1909; Denning, 1937).

Limnephilus rhombicus (Linnaeus) 1758

Limnephilus rhombicus has previously been collected in Wisconsin only from the northeast and southwest counties. One larva with a head capsule width of 1.55 mm was collected July 9, 1975, from a pool with a detritus substrate and a depth of 8 cm. Reported flight periods are June 10 to June 29 for Wisconsin (Longridge and Hilsenhoff, 1973), the end of June to the first half of July for Michigan (Ellis, 1962), and early June to late August for Illinois (Ross, 1944).

Limnephilus rossi (Leonard and Leonard) 1949a

Leonard and Leonard (1949a) described this species from adults collected September 18 to October 6 from dry grass overhanging the banks of spring-fed streams in Michigan. The larvae were not described, and the identity of those collected from Parfrey's Glen Creek remained unknown until 1977 when two males were reared September 21 and 27 from pupae or prepupae collected September 5. This is the first record of this species in Wisconsin.

Early instar larvae were collected first at the end of February. They grew slowly until the end of April, and then rapidly, reaching the fifth instar by early summer. The summer was spent in the fifth instar, with pupation in late summer. Early instar larvae were collected easily, but fifth instar larvae and pupae were difficult to find. Larvae and pupae occurred on the bottoms of rocks of all sizes and on logs over a wide range of currents. A distinct preference was exhibited for depths greater than 8 cm.

Larval description: (fifth instar): Length 16.2-18.4 mm, width 2.7-3.0 mm. Head mostly light brown with dark muscle scars most numerous on the vertex and dorso-posterior and ventral sections of the genae. Ventral half of genae medium brown, gula light brown. Frons with an anteriorly directed triangle composed of dark muscle scars. Legs light brown with infrequent muscle scars. Thoracic nota light brown with numerous dark muscle scars. Anterior edge of pronotum medium brown; posterior corners black. Mesonotum with central third of posterior margin and posterior third of sides black. Metanotum with four ovoid sclerites having 11-12 setae each. Abdominal segments 1 and 8 with 15-19 setae dorsally on each side. Gills mainly in clusters of two or three, with occasional single gills. Chloride epithelia present on ventor of segments 2-7. Anal claw with one large and one small accessory tooth.

Larval case: Constructed mainly of mineral particles averaging 0.8 mm anteriorly and 0.4 mm posteriorly with a few bits of organic material distributed randomly. Tapered posteriorly and slightly curved with a dorsal hood projecting about 2 mm anteriorly. Total length 13 to 16 mm for mature larvae.

Neophylax concinnus (McLachlan) 1871

Previous collections from Wisconsin indicate that *N. concinnus* is restricted chiefly to the northern half of the state, but it was common in Parfrey's Glen Creek. Adults were present September 6 to November 30, with peak emergence the last half of September. Sedell (1972) found emergence in this species was highly synchronized. Longridge and Hilsenhoff (1973) collected adults July 7 and September 13 in Wisconsin, while Leonard and Leonard (1949b), and Vorhies (1909) found adults flying as late as November.

Early instar larvae were first noticed in early November. They grew slowly in late autumn and winter so that by early April more than 60% were still in the third instar. Growth accelerated in late April and by the end of June nearly all were prepupae. Prepupae were found April 29 to August 15, but first occurred in significant numbers the end of June. Other workers have noted this long prepupal period for *Neophylax* (Vorhies, 1909; Lloyd, 1921). The pupal period appeared to be short, as pupae were collected only on August 15.

Early instar larvae were found mostly on stones 2 cm or larger. In currents less than 15 cm/sec larvae occurred on all faces of stones, but in faster currents they sought the downstream side or other sheltered areas. They were frequently found on large stones isolated in sandy stretches, and in spring preferred larger rocks. A few individuals were found on logs. Terminal instar larvae were often found out of the water on rock surfaces that were continually wetted. Throughout the year, larvae were found in a wide range of currents and depths.

Larvae pupated in the larval case, which they attached chiefly to rocks 8 cm or larger in currents ranging from pools to 30 cm/sec. In currents of 15-30 cm/sec pupae were found mainly in sheltered areas on the lateral and downstream sides of rocks; in pools they occurred on all sides except the bottom. Water depth did not limit distribution, and some larvae pupated so close to the water line that when the water level dropped slightly during the summer they became exposed and dried out.

Lepidostoma bryanti (Banks) 1908a

Lepidostoma bryanti has been found in all except the southeast corner of Wisconsin. In Parfrey's Glen Creek it was less abundant than the other two species of

Lepidostoma. Adults were collected April 30 to June 27, with most emerging during mid-June. They were found generally resting on tree bark and in riparian vegetation.

First instar larvae were noticed first the last week of June. They grew slowly throughout the summer and 90% were still in the third instar in late September. Growth increased greatly in late autumn and by the end of November more than half were in the fifth instar. The winter was spent as fourth or fifth instar larvae; by mid-March almost all were in the fifth instar. Pupae were found May 5 to May 28. Vorhies (1909) noted that in Parfrey's Glen Creek pupae were abundant on June 1.

Except in autumn, larvae were found exclusively in pools, the preferred substrate being leaf material and detritus. In autumn, perhaps in response to an increased need for food during their period of active growth, larvae were found on the exterior and beneath the bark of submerged logs, and were common beneath leaves. A few individuals were found in crevices or holes in rocks isolated in sandy stretches. Water depth did not limit distribution in any season.

Lepidostoma costalis (Banks) 1914b

Lepidostoma costalis was common in Parfrey's Glen Creek, but the only previous Wisconsin record is from farther north in Waushara County. Adults were collected August 2 to September 18, mostly in the last half of August. They were found most commonly resting in bark fissures.

Larvae first appeared in mid-August and grew slowly. Winter was spent as second and third instar larvae. Active growth resumed in mid-April and by late June most larvae were in the fifth instar. Prepupae and pupae were found July 24 to August 15.

In late fall and winter, larvae were found mostly in pools with a substrate of leaves or detritus, but they were also present on logs and in gravel. Larvae were found only in areas where the current did not exceed 14 cm/sec; water depth did not limit distribution. In spring, larvae were found in currents of 15 to 30 cm/sec, clinging to leaf jams in mid-stream or to rocks greater than 6 cm in diameter. Those on stones were either in crevices or on the bottom. As the larvae grew they moved back to the pool habitat and areas of very slow currents; fourth and fifth instar larvae were found only in these sites.

Pupae attached directly to vegetation in currents up to 78 cm/sec. They also commonly attached to the exterior of logs and cracks and holes beneath the bark. Pupae in pools were attached to pieces of bark, twigs, or bits of leaves. Some attached to lateral and downstream faces of rocks in the middle of sandy stretches.

Lepidostoma griseum (Banks) 1911

Lepidostoma griseum has previously been collected only from northern Wisconsin. Although uncommon in Wisconsin, it was the most common lepidostomatid in Parfrey's Glen Creek. Adults were collected August 12 to September 28, with most emerging the last half of August. This flight period is similar to that reported by Longridge and Hilsenhoff (1973), Ellis (1962), and Leonard and Leonard (1949b).

Early instar larvae were collected first on October 16. Growth was slow throughout the autumn, and winter was spent in the second and third instar. Active growth resumed in late April and at the end of June 70% were in the fifth instar. Prepupae were found on August 15; pupae occurred from August 15 to November 6.

During autumn and winter, larvae occurred in pools and currents ranging up to 30 cm/sec. The preferred substrate in pools was detritus; in riffles it was stones greater than 8 cm in diameter. In spring, when growth was most rapid, larvae concentrated in pools that had leaves and detritus as a substrate. Depth did not limit distribution in any season.

Larval cases were constructed of organic material and were similar to those of *L. bryanti,* but the cases of mature larvae differed in being shorter and stockier. Early instar larvae constructed cases entirely of small sand grains. Some fourth and fifth instar larval cases were mainly organic material, but even these always had at least a few sand grains present.

Pupae were found in currents of 4 to 31 cm/sec. They were common in cracks and holes in the bark of submerged logs, but also occurred on the underside of stones 5 to 10 cm in diameter and in sheltered areas on the lateral and downstream sides.

The three species of *Lepidostoma* coexisting in Parfrey's Glen Creek were separated temporally or spatially during periods of active growth. *L. bryanti* larvae grew most rapidly in summer and early autumn and by mid-autumn were in the fourth or fifth instar. *L. costalis* and *L. griseum* larvae grew most rapidly in late spring and early summer, and were segregated during this period, utilizing different habitats. *L. griseum* occurred almost exclusively in pools while *L. costalis* was most common in areas of moderate current and stony substrates. During periods of slow growth or pupation, no significant segregation of these two species was evident.

Summary

The 17 species of caddisflies that inhabit Parfrey's Glen Creek represent a fauna that is unusual in southern Wisconsin and more representative of faunas in northern Wisconsin streams. The small size of the stream, its low summer temperature (16.5°C), and dense woodland setting are probably responsible for maintenance of this fauna. Species competing for the same resources were found to be segregated either temporally or spatially, permitting maximum use of these resources and allowing many species to coexist in the stream. Distribution of species within the stream results from a complex interaction of environmental factors, of which current, substrate and food are probably most important.

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GARRISON LIFE IN THE NOVELS OF CHARLES KING

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Life in the "Old Army" of the Indian Wars has been admirably documented in such books as *Forty Miles a Day on Beans and Hay* and *Frontier Regulars,* both of which treat the enlisted soldier primarily as a fighting man, despite the inclusion of brief episodes of garrison life.[1] More recently *Glittering Misery* has made a conscientious effort to document the garrison life of officers' dependents in their sometimes heroic efforts to maintain islands of civilization on the western frontier.[2] But *Glittering Misery* by the sheer painstaking research that went into its composition, chiefly proves how little evidence remains for a reconstruction of garrison life among the officer class. The reasons for that state of affairs are not far to seek. First, of the innumerable letters that were written to mothers and friends back east, only a small portion has survived and few of those contain the kind of information historians desire. Second, officers' wives, after all, were no more likely to be gifted correspondents than the general proportion of educated women. And third, much of what historians now wish to know were the commonplaces of garrison social life and were omitted because of their very familiarity.

On the other hand, when officers or their wives wrote for publication they designed their works for an Eastern audience which wanted to read of Indians and picturesque frontiersmen rather than the problems of educating children in Wyoming or Arizona. Probably neither men nor women habituated to garrison life foresaw a day when army social rituals enacted in the wilderness would seem as exotic as the Indian rituals they supplanted. Moreover, publishing memoirs was complicated by conventions decreeing that few people could be named in such memoirs and circumscribing what could be said even of those. Nineteenth century decorum threw a fierce privacy about a "good" woman. Even in conversation a gentleman spoke only of "my wife" or "Mrs. _____." He never employed her given name except among her intimates. He could not describe his wife's activities or those of other officers' wives without giving offense. In consequence even married officers so completely omitted accounts of social life from their recollections that on a first reading their books appear to have been written by bachelors.[3]

In the absence of detailed and even gossipy diaries, perhaps the best pictures of garrison life available to historians today are those created by the Milwaukee novelist, General Charles King (1844-1933) who had served in the Indian fighting army before turning author. General King was the son of the editor of the Milwaukee *Sentinel.* He grew up in Milwaukee and began his military career by serving as an aide to his father, General Rufus King, during the Civil War. He subsequently graduated from West Point, served briefly as an instructor there, and after being stationed at New Orleans requested assignment to Arizona where he took part in the Apache campaign of 1874. He was severely wounded at Sunset Pass and awarded the Silver Star for "gallantry in action" at Diamond Butte. His regiment, the 5th cavalry, moved to Wyoming for the Sioux campaign of 1876-77 during which King was promoted to Captain and shortly thereafter retired because of disability due to his earlier wounds. He returned to Milwaukee where, because his account *Campaigning with*

Crook had been published by the *Sentinel,*[4] he already enjoyed a literary as well as military reputation, and turned to novel writing as a means of supplementing his retirement pay. He was recalled to service during the Spanish American War, serving in San Francisco and Manila and participating in the defense of Manila during the Philippine Insurrection which followed. Once more he returned to Milwaukee and novel writing. Although he was active in the Wisconsin National Guard and trained troops for World War I he was not permitted to go overseas in that war. He remained a familiar figure in military and social circles in Milwaukee until his death in 1933.

He employed all his military experience in the approximately sixty volumes of novels, stories, and histories which he published during his lifetime, but his best and most interesting novels are those laid on the Great Plains or in Arizona during the years 1871-78, particularly the group of novels in which he follows the fortunes of a cavalry regiment, rather like the 5th Cavalry, from Arizona to Wyoming.[5] In these novels he drew heavily upon his own experiences and, in fact, probably appears in them in the secondary role of Billings, the adjutant.[6]

Because he unabashedly wrote to make money, King developed a fool-proof plot formula which combined a garrison love story with one or more episodes in which the cavalry is hotly engaged against hostile Indians, thus assuring his readership among both men and women. When his garrison plots are stripped of such obvious plot devices as concealed identities, mistaken identities and service in the field, a reader discovers that a fourth reason so few officers' wives kept diaries or wrote their recollections was the same reason that drove trooper Charles E. Springer to discontinue his daily journal, "to repeat day for day the life of a frontier garrison in winter is no charm."[7] Winter or summer, garrison life was more notable for its sameness than its variety. The degree of hardship undergone in following one's officer husband might vary with the distance to the nearest railhead; the chief discomfort might be heat or cold, sandstorms or blizzards, depending upon the geographical location of the fort; there might be many women or few, depending upon the size and remoteness of the fort; but army routine and army protocol were the same. Everywhere their husbands were posted, the women awakened to the same bugle notes and made the same duty calls among virtually the same people. In King's novels, whether laid in Arizona or on the great plains, it is the routine and predicability of garrison life which forms the background for the action of the plots and, in fact, sometimes sets the plots in motion. Ennui drives garrison inhabitants to seek new amusements and focuses their attention upon minor infractions of social or military convention.

Even the passage of years did not alter army routine; although it added new forts to the frontiers and slowly and subtly changed the composition of the officer corps.

In King's early novels, the majors and colonels who commanded posts were usually veterans of the Civil War who had risen to command by service in the Union Army. Among them were men who held brevet rank considerably higher than their permanent army rank. Men such as these, without formal military training, might be admired by their troopers, but in King's novels were eyed askance by their subordinate West Point officers unless they were truly exceptional commanders.[8] The young first and second lieutenants and some of the captains were usually West Point graduates, often the sons of army officers who, like King himself, were carrying on a family military tradition. The social uneasiness generated by a situation in which the West Point men were often outranked by men they considered their social inferiors was not dissipated until, with the passage of time, King's West Point heroes rose to command. Under those conditions an officer's wife needed the diplomatic skills of an ambassador to prevent being drawn into one camp or another, but such social manuevering is a subject better fitted for a novel than for memoirs.

King wrote about the officer class not only because it was the class he knew best but probably because as Fred Dustin has commented, "In 1876 the average enlisted man counted for little: in the army he was only a number on the rolls. By the comfortable civilian he was despised."[9] King created a few vivid and sympathetic sketches of cavalry troopers but he almost completely ignored their wives. Although there was an area of each post known as "sudsville" it constituted an entirely separate social entity. Even when, as in the novel *Captain Blake,* troopers and their wives attended a play produced by the officers, they were seated in a separate section from that reserved for officers and their wives.[10]

Although in King's garrison novels, money was never an acceptable substitute for courage or breeding, officers were expected to have private means by which to supplement their pay. It was axiomatic that a lieutenant could hardly maintain himself, much less a wife and family, upon his officer's pay. Precisely because garrison life was remote, it was also costly. Household goods had to be transported long distances and were expensive upon the frontier. In addition there were visits to be made to aging parents, and son and daughters to be sent away to appropriate Eastern schools. The sons in these novels often followed in their father's footsteps at West Point. The women vacationed near West Point in order to visit their sons and brothers and to meet eligible young officers. As a result of army marriages, garrison society was knit not only by bonds of comradeship but by ties of blood.

The education of officer's daughters was obtained in good finishing schools rather than colleges. None of the women in King's novels was bookish, although a few of the young officers had scholarly interests. In fact, although army wives supervised the children's lessons, in King's novels they were rarely seen with books in their hands except when reading to invalids. Neither did they do much sewing, usually buying or ordering their clothes on trips to Chicago or New York. Paris couture was a matter for comment, but dresses from the East were commonplace.

Officers' daughters became officers' wives at 18 or 19 in many cases, so that in these novels they were often ten years younger than their husbands. Families, however, were small and that fact combined with the presence of servants freed the women from the demands of domesticity. Many of the women rode well and several of the wives who had grown up in frontier garrisons could handle a Smith and Wesson revolver competently. These were women whom King and the garrison unanimously approved.

Once married, King's heroines conducted their domestic lives in a succession of adobe or drab frame houses constructed by army labor. Most of them were built as double houses with a common wall.[11] They varied somewhat in overall size and in the number of bedrooms, but all were shaded by verandas facing the parade ground. They usually ended in lean-to kitchens giving upon small yards bounded by a low fence. They had at best only partial basements, or cellars. In summer the wooden walls cracked and peeled under the heat of the plains winds; in winter the foundations were banked with straw and the snowdrifts piled to the second story. Gales from the mountains swayed the Navajo blankets (brought from Arizona) hanging across the interior doorways, despite storm sashes and the layer of cotton stuffed around the windows. The carpets, stretched over several thicknesses of newspaper, rose and bellied under the force of winter winds. Parlor and kitchen stoves provided heat and kerosene lamps, light, during the long winter evenings. The cry of "fire" echoes through General King's novels somewhat monotonously, but undoubtedly reflects an ever-present danger. Whether because of the possibility of fire or because there was no suitable storage place provided, in at least two of King's novels the family silver seems to have been kept in a box or basket under the bed when it was not used for entertaining.[12]

Such were the houses available to the officers and their wives. And even these were assigned by rank. One house, the largest and best, was designated for the Colonel commanding. Two houses, on larger posts, might be generally considered to belong to the majors. Thereafter the captains chose their quarters in order based on the date of their promotions. The 1st Lieutenants followed, also in order of promotion and finally the 2nd Lieutenants, almost invariably bachelors, doubled up in the houses no superior had claimed. An officer newly transferred to a post had "bumping rights" over all his subordinates so that he had the power to set off an elaborate series of housing shifts each giving rise to politely concealed ill-will. King illustrates the operation of this ritual when an entire regiment was assigned to a new post.

> The bachelor officers pitched tents on the parade and placidly waited their turn to choose quarters, a ceremony which impressed Miss Leroy as something incomprehensible. It was not easy to make her realize just why Captain Ray couldn't move Mrs. Ray and the baby boys up from the hotel until Captain Freeman had chosen, and why Mrs. Blake should remain at Cheyenne near her old home until the Truscotts and Rays had settled on what houses they would take. (They wanted the big double brick next but one to the Colonel's, but were afraid to move in, lest the new surgeon ordered out from Omaha should take a fancy to that very set.)[13]

It is no wonder that seasoned army wives like Mrs. Stannard who appears in many of King's novels learned to live with as few chattels as possible. But beyond the inconvenience of housing shifts there was another crueler consequence of the limited post housing. An officer killed in action was promptly replaced on post. That meant that his widow was forced to vacate her house, leaving behind not only the army life that she knew but the friends who could best understand her grief and bewilderment.[14]

In addition to the officers and their families, garrison houses often accommodated live-in servants. Bachelor officers had army strikers to serve them, but married men employed either a combination cook and housemaid or both. In families with children a nursemaid was not uncommon. Such servants were drawn from diverse sources, but the majority of the servants in King's novels were Irish. Sometimes a veteran trooper no longer fit for military service took civilian service with an officer in order to stay with the life he knew. The wives and daughters of troopers were also employed by officers' households, but since many of the troopers were Irish they and their families merely swelled the Irish servant brigade. These servants were important in King's novels, as they probably were in life, because they provided a channel of unofficial communication between the troops and the officers' households. They formed an excitable, gregarious society from which the Blacks, Chinese and the occasional Indian girl were largely excluded. However an immeasurable gulf separated a pretty Irish servant girl from the daughter of the house. The servant girl could be courted by troopers; the daughter of the house only by officers. Despite the scarcity of women on post, in King's novels no young officer ever falls in love with an

Irish servant girl. On the other hand, Mrs. Snaffle and Mrs. Wilkins, captain's wives, lapse into brogue when excited, thus suggesting that officers of an earlier generation had been less fastidious.[15]

The lives of all these people, officers, troopers, wives and servants, moved to the measure of trumpet calls and focused, in good weather at least, upon the parade ground. Each day began with the boom of the morning gun and ended with the sunset gun. Between those events the trumpet called Reveille, Stables (this was a cavalry regiment), Sick call and Fatigue, Boots and Saddles for morning parade, Adjutant's call, Guard mounting, Drill call, Recall, Dinner, Squad drill, Company drill, Stables, Retreat and Evening Dress Parade.[16] After the Sunset Gun it called Tattoo, and Lights Out, although those calls spoke only to the barracks. No village clock ever regulated lives as rigidly as did those trumpet calls. They also had power to disrupt lives—to sound "officers call" or more importunately "the General" (general assembly) at any hour; thus sending troops and their officers to intercept Indians off reservations, to relieve some beleaguered stage station, or to quell riots in town. In King's novels men welcomed "the General" almost as fervidly as women dreaded it.

As the day was ordered by trumpets so the night was divided by sentry calls. The sentries posted on the perimeter of the garrison did not walk beats which met. Instead, at regular intervals, they called off and the sound moved in order around the post. Like Tattoo and Lights Out the call of the sentries did not concern most of the officers, but only the Officer of the Guard.

For the other officers and their wives evening parade signalled a transition from business to pleasure, from army time to time that might be called their own. Evening parade was not only a military but a social event. The women of Officers Row, freshly dressed and at leisure before dinner, sat on the verandas facing the parade or strolled from house to house to exchange the day's news, to admire their husbands in dress uniform to watch parade and listen to the band. Even small posts maintained a band and large forts such as Russell and Cushing prided themselves on the excellence of their music. As parade broke up, the officers, released from their day's routine, had time to join their wives and friends. Courtesy required that all acquaintances be acknowledged and since everyone knew everyone else the way homeward was more social than military.

Bachelor officers might go to the post or trader's store, there to get a drink and settle down for an evening of poker. Married officers sometimes joined them briefly. Although a room at the store was usually the only approximation of an Officers' Club, the officers who spent too much time there were suspect in King's novels. If married, they were assumed to frequent the club because they did not get along with their wives; if single, because they were unable to command invitations to the better homes on the post. The cardroom, King implied, attracted grumblers, created ill will, and fomented the male equivalent of female gossip.

Generally the social life of the Garrison was orderly, decorous, and predictable. There were frequent invitations to dine, but since rooms were small, dinner parties of more than ten were practically unknown. However there was a great deal of casual calling and stated occasions when formal calls were *de rigeur*. Thus dinner required a proper dinner call the following day. All guests in the garrison and all new families posted to the fort were to be called upon immediately. Engagements, birthdays and promotions required calls of congratulation, and bereavement calls of sympathy. All these were the common courtesies of a somewhat formal age, and would have been conducted equally punctiliously by ladies and gentlemen in any Eastern city. However, garrison social life produced some distinctive patterns. For one thing many of the wives, all in fact of the most admirable in King's eyes, did not entertain while their husbands were off on campaign. When three or four troops were out of the fort this convention necessarily created periods of social doldrums even during the winter, when the social season was at its height. During the summer, the usual campaign season, the effect was exaggerated by the fact that many wives summered in the East.

When wives returned in the fall they often brought guests to spend the winter. One might suspect that the number of attractive feminine guests thus introduced to fort society was merely a device employed to provide the love interest General King required for his plots. However, a story which might have been written by General King himself is contained in the memoirs of General Cruse. His wife's sixteen year old sister spent the winter at Fort Lowell, was courted by Lt. Hodgson over the family objections that she was too young, and married her cavalry officer the following year.[17]

The Custer's, also, apparently made a practice of inviting pretty girls for extended visits.[18] Thus Elizabeth Custer's narratives of life in the Plains forts serve to substantiate the pretty roommates, cousins and nieces who enliven garrison life in King's novels.

For entertainment these girls were offered dinners with the middle aged, the spectacle of parade, informal evening parties, escorted rides into the surrounding country, skating on the Platte, sleigh rides after sufficient snowfall, band concerts, an occasional formal German and even amateur theatricals. In suitable fall weather there might also be a jack rabbit hunt over the hills, ending in a picnic to which the ladies who neither rode nor hunted were conveyed by ambulance. The chief entertainments, however, were the frequent informal dances, or hops. When young Mrs. Turner complained bitterly that the hops, held almost nightly in Arizona, were less frequent in the Wyoming garrisons, Mrs. Stannard explained that in Arizona the band had not been mounted and therefore did not have to attend morning and evening stables.[19] Therefore, evening duty for hops was not an unreasonable demand upon them. Since the bands in Wyoming were mounted, nightly hops would be an unwarrantable imposition even though hops broke up early. In fact all the social life of the garrison except the most formal dances ended by eleven or twelve o'clock. The army world believed in early to bed and early to rise. Stable call, attended by the officers, sounded at 6:00 a.m.

Although much of an officer's life was regulated by official duties and protocol there was another, generally female, side of garrison life not subject to official rules. Secrets and news, passing through official channels among the men, passed also from veranda to veranda among the women, and from kitchen to kitchen among the cooks. Cut off from their families women supported each other through illnesses and bereavements. Their hospitality was boundless, for new faces and new conversation were both welcome means of enlivening garrison social life. Not only were guests invited for months, but the same generosity was extended to the relatives of bachelor officers, to wives until they were settled on a post and to young officers convalescing from wounds. Women lent silver, dishes and recipes, sat with invalids, encouraged courtships, wrote innumerable letters linking garrison to garrison and frontier to families in the East, mentored young officers, read weeks old newspapers, and speculated on their next removal. In such enterprises the women were restrained only by their own discretion and their husbands' authority. And therein lay the danger.

Duane N. Greene wrote in a sketch of army life that "The most discordant garrisons are those comprising the greatest number of ladies."[20] Novelist King, despite his frequent praise for Officers' wives who left comfortable Eastern homes to follow the cavalry into frontier garrisons, tends to substantiate Greene's pronouncement. Women were at the root of almost all garrison trouble in his novels. Mrs. Pelham interferred in the promotions and leaves granted her husband's men.[21] Mrs. Turner gossiped until her husband's friends one by one deserted him.[22] Mrs. Wilkins was the terror of social engagements despite her warm heart.[23] Nanette Flower proved a spy and a traitor[24] and Mrs. Granger enthralled Tommy Hollis and Captain Blake for her own ends.[25] Younger women disrupted the post by their very presence—two of them attracted undesirable kinsmen to the area of the fort.[26] Other girls evoked rivalries between officers. It may seem unreasonable to include male rivalries in the list of women's derelictions, but King himself raised the issue in *Marion's Faith* when he wrote "Things were in almost as eruptive a state at Russell . . . as they had been at old Sandy during the Pelham regime, only—only who could this time say there was a woman at the bottom of it? And yet was it not Gleason's unrequited attention to our heroine that prompted much of the trouble?"[27]

Taken altogether the roles of women in General King's novels are fairly unambiguous. The women he admired, the women he assigned to his heroic officers as rewards for valor and patience, proved to be fine wives, but they served the garrison by their discretion and their adoption of the officer's code. They became army. Other women, and even those before their marriages, were sources of disruption. Since the army could not drill women into shape like a slack cavalry troop, it was with a sense of real relief on the part of both author and characters that men took the field. Once on campaign the desirability of order and discipline became self-evident and the foe could be neatly identified by his warpaint. When King's officers responded to "the General" they moved from a world complicated by women to the simpler, if more violent, world of primal landscapes and single purposes. In King's novels they went gladly, for as Captain Ray, one of King's chief heroes announced profoundly, "Garrison life and girls spoil many a good cavalryman."[28]

Notes

[1] Don Rickey Jr., *Forty Miles a Day on Beans and Hay* (Norman, Oklahoma, 1963), Robert M. Utley, *Frontier Regulars* (New York, 1973).

[2] Patricia Y. Stallard, *Glittering Misery,* Dependents of the Indian Fighting Army (San Rafael, California, 1978).

[3] General Crook refers to "Mrs. Crook" only in two consecutive paragraphs. *General George Crook, his Autobiography* ed. Martin F. Schmitt (Norman, Oklahoma, 1946) p. 155. General Miles refers once to "my wife" and once, mentioning the Custers at Fort Hays, says "Mrs. Miles being with me, we frequently met them socially and enjoyed many hunts and pleasure parties together." Nelson A. Miles, *Personal Recollections of General Nelson A. Miles* (New York, 1969) pp. 151, 256. George A. Custer, *My Life on the Plains* (Norman, Oklahoma, 1962) refers to his wife once as "Mrs. Custer" and once as "my wife," pp. 68, 66.

[4] Campaigning with Crook was first published serially in the *Sentinel* and then in a paperbound edition (Milwaukee, 1880 before being published by Harper and Brothers, New York, 1890.

[5] Charles King, *The Colonel's Daughter* (Philadelphia, 1882). Charles King, *Marion's Faith* (Philadelphia, 1886). Charles King, *Captain Blake* (Philadelphia, 1892). Although the characters introduced in *The Colonel's Daughter* appear in, or are mentioned in, other novels by King, the three listed here are the most important to the history of King's fictitious regiment.

[6] For King's employment of his own experiences see Harry H. Anderson, "Home and Family as sources of Charles King's Fiction," Milwaukee County Historical Society *Historical Messenger*" 31:68 (Summer, 1975).

[7] Charles E. Springer, *Soldiering in Sioux Country, ed.* Benjamin Franklin Cooling III (San Diego, 1970), p. 73.

[8] In King, *Marion's Faith,* Colonel Whaling and his wife are condescended to by almost all the cavalry officers. Also in Charles King, *Ray's Recruit* (Philadelphia, 1898) Capt. Mainwaring is a decent officer whose selfconsciousness about

his lack of formal education makes him the butt of some of the younger officers' humor.

[9] Fred Dustin, in W. A. Graham, *The Custer Myth* (New York, 1953), p. 369.

[10] King, *Captain Blake,* p. 190.

[11] The composite description derived from King's novels can be compared with the following descriptions from the annual inspection of public buildings which appears in Richard Upton, *Fort Custer on the Big Horn* (Glendale, California, 1973).

No. 6. Commanding Officer's Quarters, frame, single set, 1½ stories, size 42 by 36 feet, four rooms on each floor; "L" to same embracing kitchen, pantry, closets, with attic chamber; size 20 by 16 feet. Porch in front.

No. 1 to 5, and 7 to 11. Officer's quarters, frame, ten double sets, 1½ stories, size 48 feet by 46 feet six inches, six rooms on first and four rooms on second floor; "L" to same, size 34 by 14 feet embracing two kitchens, with pantries, closets and attic chambers. Porch in front." p. 280.

[12] Charles King, *A Daughter of the Sioux* (New York, 1903), p. 215 and Charles King, *A Garrison Tangle* (New York, 1896), p. 163.

[13] King, Ray's Recruit, p. 102.

[14] Mrs. Farrar is widowed in Charles King's *Fort Frayne* (New York, 1895), Mrs. Turner in *Captain Blake* and Mrs. Winn in Charles King's *A Trooper Galahad* (Philadelphia, 1898).

[15] Charles King, *Lanier of the Cavalry* (Philadelphia, 1892) and *The Colonel's Daughter.*

[16] This list (which is not exhaustive) is based on a list of calls in Charles King, *Trials of a Staff Officer* (Philadelphia, 1895), p. 15.

[17] Thomas Cruse, *Apache Days and After* (Caldwell, Idaho, 1941), pp. 181, 191.

[18] Elizabeth Bacon Custer, *Tenting on the Plains,* 1887 (reprinted Williamstown, Massachusetts, 1973) p. 208.

[19] King, *Marion's Faith,* p. 35.

[20] Duane N. Greene, *Ladies and Officers of the United States Army; or American Aristocracy, A Sketch of the Social Life and Character of the Army* (Chicago, 1880).

[21] King, *The Colonel's Daughter.*

[22] King, *Captain Blake.*

[23] King, *The Colonel's Daughter.*

[24] King, *A Daughter of the Sioux.*

[25] King, *Captain Blake.*

[26] King, *A Garrison Tangle, Lanier of the Cavalry.*

[27] King, *Marion's Faith,* p. 314.

[28] King, *Ray's Recruit,* p. 40.

AGENTS OF THREE NATIONS IN THE FOX RIVER VALLEY, 1634 TO 1840

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While explorers, fur traders, Indians, priests and a very few white settlers were the major actors in the early history of the Fox Valley, an impressive number of noteworthy events were set in motion by people carrying out the policies of distant governments.

FRENCH ERA TRAVELERS THROUGH THE FOX VALLEY 1634-1763

The first government to wield any sovereign authority in the present-day Fox Valley of northeastern Wisconsin was the colonial government of French Canada. Permanent French settlements were established at Quebec in 1608, Three Rivers in 1634 and Montreal in 1642. Only twenty-six years elapsed from the founding of Quebec to the day when Jean Nicolet, an official emissary of Governor Champlain, fired his pistols and wore his finest damask robe to impress Winnebago Indians at Red Banks northeast of Green Bay. Nicolet's arrival within the boundaries of present-day Wisconsin was the first expression of European authority in the Fox Valley wilderness.

The first reference on any map to the Fox River Valley was a map drawn by Jean Boisseau at Paris in 1643 which shows the Fox River (Riviere des Puans), Lake Winnebago (Lac des Puans), and the tribal region in which the Winnebagoes resided in 1643 (La Nahon des Puans). The map references to the Winnebagoes presumably came from hearsay reports obtained by Nicolet from Indians familiar with the topography of the Fox Valley.[1]

The first official agents of governmental action in the Fox Valley appear to have been the seven members of the Louis Joliet expedition. Joliet and his interpreter-cartographer-chaplain associate, Father Jacques Marquette voyaged up the Fox River in late May and early June of 1673 at the order of Canadian Intendant Talon to investigate reports that there was a great river in the west of New France called the Mississippi.[2] Father Marquette's map accurately shows the Fox-Wisconsin river system including Lakes Winnebago and Butte des Morts, indicates the Wolf River and sketches correctly the Illinois River from the Mississippi (R. de la Conception) to Lake Michigan (Lac des Illinois).

The first large scale governmental action within the Fox Valley was the invasion in 1716 by a French military expedition during the First Fox War. The French "army" was organized at the order of Canadian Governor Philippe Vaudreuil and commanded by the King's Lieutenant at Quebec, French Army Major Louis de la Porte, Sieur de Louvigny. The force consisted of some 225 French soldiers and fur traders, and 600 armed Indians, two brass cannon and a brass grenade mortar. Louvigny's orders were to clear the Fox River of all hostile blockading forces, including a fortification of the Fox Indians located on the southwestern shore of Big Lake Butte des Morts.

The Fox fort, some four miles west of the present-day site of Oshkosh and a short way east of the main Fox village on Big Lake Butte des Morts was described by Father Pierre F. X. Charlevoix, the expedition's chaplain, to his Jesuit superiors, as a "sort of fort surrounded by three ranges of oak palisades with a good ditch in the rear." Both Louvigny and Charlevoix said the Fox fort was garrisoned by 500 warriors (300 additional warriors were absent on a war party) and 3,000 women.

Louvigny bombarded the Fox fort with his two cannon and grenade mortar, until

> "On the third day . . . while I was preparing to undermine their works by placing mine boxes under their wall the Foxes proposed terms of capitulation . . . and I . . . concluded peace with the Foxes.[3]

Records of Louvigny's siege do not indicate the fort's exact location, but in "The Bell Site: an early Fox village" archaeologist Warren Wittry reported finding iron grenade fragments on the southwest shore of Lake Butte des Morts, thus suggesting that:

> ". . . this site might be the one attacked by Louvigny in 1716 . . . So far as is known to the writer, the grenades fired by Louvigny are the only ones ever shot in central Wisconsin. . . ."[4]

The First Fox War ended in 1716 and the Second Fox War began in 1728, largely because the Foxes, according to Father Charlevoix:

> "infested with their robberies and filled with murders not only the neighborhood of Green Bay, their natural territory, but almost all the routes communicating with the remote (French) colonial posts."[5]

Canadian Governor-General Beauharnois, desiring to end the Fox Indians outrages, believing French lives must not go unavenged and being determined to overawe both the Iroquois and the Foxes by a brilliant stroke, sent a second military force to present Winnebago County in the summer of 1728. Commanded by Constant Marchand, Sieur de Lignery this force, consisting of 400 French and 1,100-1,200 Indians left Mackinac August 10, 1728 and advanced along Green Bay in bateaux and canoes (Fig. 1). Lignery provoked and then defeated the Menominees on August 15th and reached the west end of Big Lake Butte des Morts by August 25th.[6]

Having had timely notice of the French army's approach, and lacking warriors to match Lignery's force, the Foxes retreated up the Fox River and into the forests west of Omro, where Lignery felt it imprudent to pursue them.

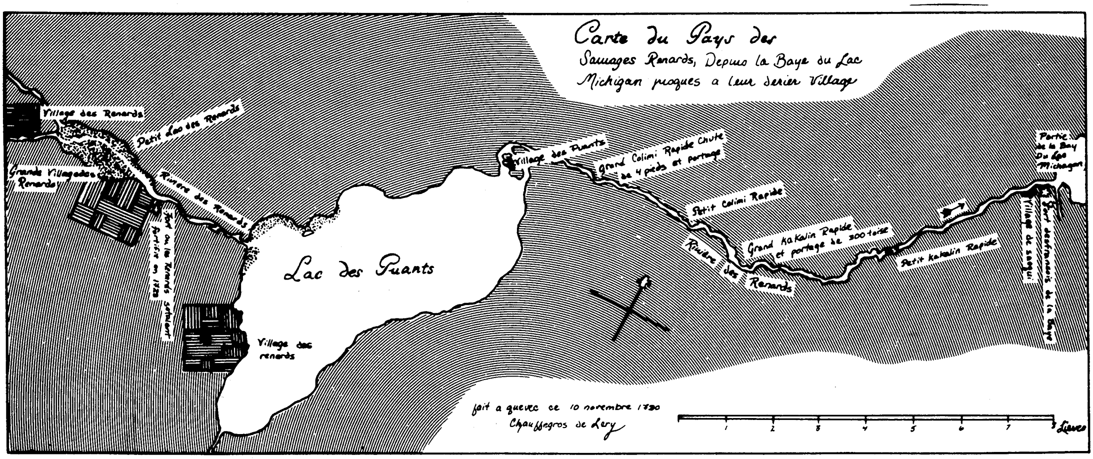


Fig. 1. This "Map of the Land of the Savage Foxes," was published in 1730 by Gaspard Chaussegros de Lery, to illustrate his account of the Lignery expedition's attack in 1728 on the fort of the Fox Indians, then resident on Big Lake Butte des Morts and Lake Winnebago in east central Wisconsin. De Lery's map appears to be the first to show details of the Fox River valley including vicinities of present day Omro, Oshkosh, Appleton, Kaukauna, and Green Bay. Source: L. P. Kellogg, *French Regime in Wisconsin* (1925), 314.

Lignery remained at Lake Butte des Morts only briefly because his army had to return to Montreal before the rivers froze and the first snows fell. Consequently he was able only to burn the Fox villages and destroy their unharvested cornfields and gardens. In retreating down to Green Bay, Lignery withdrew the La Baye garrison and burned the fort since his expedition had chiefly succeeded in infuriating the Foxes without inflicting significant damage. Lignery concluded that the small fort at Green Bay would not be able to defend itself against the certainty of revenge attacks in the following fall and winter.[7]

Weighed on a scale of military success or failure, it would seem that it was the Foxes, not the French who were victorious. Actually, a delayed consequence of Lignery's invasion of 1728 was that the Fox Confederacy of anti-French tribes suddenly began to crumble. News came to the Fox villages on Lake Butte des Morts that their Kickapoo and Mascouten allies had made peace with the Illinois Indians. At the same time the Sioux refused to continue their agreement to grant the Foxes refuge in Sioux country if they could not resist the onslaught of the French. Perhaps most upsetting to the Foxes was the fact that Montreal was crowded in 1729 with delegates from western tribes of the upper Great Lakes, all declaring their love for the French and their hatred for the Foxes.

Canadian Governor Beauharnois now changed his commander. Paul Marin, former commandant at Fort La Baye was selected to lead a third expedition against the Foxes in 1729. Marin's party left Montreal in the summer of 1729 but he came only as far west and south as the vicinity of former Fort La Baye, where he wintered. Early in the spring of 1730 a great military opportunity suddenly presented itself to Marin. A portion of the Winnebago who had deserted the Fox confederacy returned to their village site on Doty Island in Lake Winnebago and were suddenly attacked by a large force of Foxes. Marin's party hurried to the assistance of the Winnebagoes with a force of Menominees and a few fur traders. After five days of grim fighting the Foxes broke off their attack during the night.[8]

Disasters now began to fall on the Foxes like hailstones. One was an incredible effort in 1730 to move the entire tribe to present-day New York state to seek refuge among the Iroquois who had long solicited their alliance and had offered them asylum. This effort was thwarted by the cooperation of the French settlements at St. Joseph and Detroit, Michigan; in the Illinois Valley; at Vincennes, Indiana and Miami, Ohio, which raised a combined force of 1,400 French and Indians to besiege the Foxes who had halted and erected a fort on the Illinois prairie on an eastern branch of the Kaskaskia River. The Foxes defended their position for 23 days, abandoning it under cover of darkness and a storm on September 9, 1730. Next day, the Foxes, burdened with their families, were overtaken and two or three hundred warriors with an equal number of women and children were massacred. Four or five hundred more were captured and scattered as slaves among the Indian allies of the French. Only several hundred Foxes escaped and fled back to Wisconsin.[9]

Another disaster befell the Foxes in the winter of 1731-32 when Governor Beauharnois connived at the departure from Montreal of a war party of mission Indians who came to Wisconsin to "eat up Reynards." Proceeding part of the way overland on snow shoes, the mission Indians attacked a Fox village of fifty cabins on the Mississippi River about five miles above the mouth of the Wisconsin River, killing or capturing 300, only "thirty 'true' Reynards" escaping.[10]

It was a poignant disaster for the Foxes when war chief Kiala and three fellow chiefs surrendered themselves to Commandant Villiers at Fort La Baye as hostages to the French, in the hope the remainder of the

Fox tribe would be spared. Instead of being merciful, Governor Beauharnois condemned the Fox chiefs to a slow death by chain gang labor and tropical heat at a sugar cane plantation on Martinique.[11]

The crowning Fox disaster came in September, 1733. Captain Villiers returned to Fort La Baye with orders from Governor Beauharnois to exterminate all remaining Foxes; men, women and children. When rumors of Villiers' orders reached the Sauk village at La Baye, the Sauks were seriously alarmed, as they had permitted the few remaining Foxes to take refuge with them in their village. If the French were to insist on the surrender of the Fox refugees, the Sauks would be forced to break the customary Indian obligation of hospitality and protection to their persecuted relatives. Their alarm would have been even greater had they realized that the stage was being set for the bloodiest battle ever to occur in Winnebago County, the Battle of Little Lake Butte des Morts.

When Commandant Villiers walked up to the locked gate of the Sauks' palisaded village at La Baye on September 16, 1733 with less than a squad of the more than 300 garrison troops, fur traders and allied Indians under his command and rashly tried to break open the gate, a shot from within the village killed one of Villiers' sons. Villiers angrily returned the fire, at which a twelve year old Sauk in one shot killed the commandant. A brief fire fight at the Sauk gate now ensued in which ten French attackers, including Repentigny, second in command at Fort La Baye, were killed and three others wounded.[12]

When the Sauk chiefs realized this much French blood had been shed they also realized that French retribution would come quickly and that they had no alternative but to retreat from La Baye as quickly and secretly as possible. The Sauk-Foxes left their village under cover of darkness on the third night following the fight at their village gate, proceeding up the Fox River.

The next day the dead commandant's oldest son, Ensign Louis Villiers, organized a pursuit force of most of the La Baye garrison plus whatever fur traders were in town. Villiers' party overtook the fleeing Sauk-Foxes by late afternoon at a point somewhere close to the present-day high level bridge across Little Lake Butte des Morts. The historic Battle of Butte des Morts then began. According to Louise Kellogg:

> "The French lost heavily as well as the Sauk-Foxes. Among the French officers alone, one or more members of the Villiers, Ailleboust, Du Plessis and other well-known families, mourned the death of their youth. . . . Ensign Louis Villiers was wounded and Augustin Grignon recalled at a later time that two of his uncles were killed in this battle. It is believed that the great mound at (Little) Butte des Morts was erected to cover the tribesmen slain in this battle."[13]

Canadian Governor-General Beauharnois reported to France on November 11, 1733, that the losses of the French and their Indian allies at the Battle of Butte des Morts were 34 dead and about 20 wounded. These casualties were in addition to the ten killed at the Sauk-Fox village gate. The Sauk-Fox left 20 Sauk and six Fox dead on the field and had an unknown number killed and wounded.[14]

The Sauk-Foxes who could travel now abandoned the Fox River country, moved west of the Mississippi, found refuge among the Sioux and built a palisaded village on the Wapsipinicon River in eastern Iowa. Years later they established themselves for several generations on the lower Rock River in northwestern Illinois. After the Battle of Butte des Morts, several other tribes, secretly pleased with the resistance of the Foxes, returned their Fox captives, so that Sauk-Fox numbers in Iowa and Illinois again became substantial.

The final French effort to exterminate

the Foxes in the Second Fox War was a winter expedition in 1734-35 organized at the order of Governor Beauharnois and commanded by Captain Nicolas Joseph de Noyelles. De Noyelles' force consisted of 84 French soldiers, habitants and 200 mission Iroquois Indians. When de Noyelles moved up the Fox Valley, winter had already begun. Abandoning their canoes and proceeding on snow shoes, de Noyelles finally found the tribesmen he sought in early April, 1735, fully entrenched on an island in the Des Moines River. After futile attacks in which several French officers were killed, de Noyelles abandoned his objective, his party making their way to the nearest French settlement south of present-day St. Louis.[15]

When the chiefs from the upper country, assembled at Montreal in 1737, asked for mercy for the Sauks and Foxes, Governor Beauharnois agreed and sent Pierre Paul Marin to conciliate them. Marin succeeded, first at an Iowa post and later at a trading post among the Sioux on Lake Pepin.

When friction between French and British colonies in North America developed into armed conflict in 1755, French governmental recruiters and their Indian enlistees passed through the Fox Valley repeatedly. Paul Marin and Charles de Langlade both recruited and commanded increasingly large contingents of Western Indians in support of French Canada. Langlade and his Indians were sent home in 1760 only a few days before the surrender of the final French Canadian stronghold, Montreal, to British General Amherst. Langlade brought the news to Mackinac and La Baye that all of French Canada had surrendered to the English on September 8, 1760.

The last French governmental force to traverse the Fox-Wisconsin was the combined garrisons and officers of fort Mackinac and La Baye, commanded by Captain Louis Beaujeau. They retreated up the Fox River in October of 1760 and ultimately reached New Orleans. The French era in Wisconsin was at an end.[16]

British Era Travelers Through the Fox Valley 1763-1816

Jonathan Carver in 1766 was the first Englishman to travel up the Fox Valley, and Peter Pond, in September, 1773, was probably the first Yankee to travel from Green Bay to Prairie du Chien.[17] Neither Carver nor Pond came to the Fox Valley as a consequence of any governmental policy. However, during the American Revolutionary War, it was British policy that caused Charles Langlade of Green Bay to lead Wisconsin Indians to Quebec in 1776, 1777, and 1778. Some of Langlade's Wisconsin Indians supported British General Burgoyne's campaign in upstate New York and became a scourge to American frontier settlements.

In 1780 Menominee and Winnebago Indians accompanied the unsuccessful British attack of Emanuel Hess on the American fort at Cahokia (East St. Louis) and the Spanish fort at St. Louis. George McBeath, a fur trader and interpreter for Langlade, was the last British traveler along the Fox-Wisconsin having a role in the American Revolutionary War. He announced to a council of tribesmen at Prairie du Chien on May 24, 1783, the approach of peace and advised the Indians to devote their future energies to hunting.[18]

Once the United States had become an independent nation, its sovereignty extended west to the Mississippi and north to the Canadian border. Wisconsin supposedly was American. In reality British fur traders continued to operate at will throughout the area. Wisconsin Indians were British in sympathy and the Wisconsin fur trade functionally was still Canadian.

It was about May 1, 1812, that Francois Reaume, a secret courier from Canadian General Isaac Brock, passed along the Fox-Wisconsin with an urgent message for

Robert Dickson, chief trader at Prairie du Chien for the Northwest Company. General Brock's message to Dickson, who now became a colonel in the Canadian army, warned of the near approach of war between Britain and the United States and in guarded terms suggested Dickson begin recruiting Indians. In the ensuing months, hundreds of Indians from the Sioux, Sauk, Winnebago and Menominee tribes, Including Menominee Chief Tomah and his protege Oshkosh and 200 Sauk-Fox warriors under Sauk Chief Black Hawk reported to Robert Dickson for British military duty.

A British surprise attack on Fort Mackinac captured the American island fortress in the War of 1812 before the American garrison even knew war had been declared. The British had not only prepared for war by inflaming Indian tribes against the Americans, but had secretly set their various forces in motion before the actual outbreak of war, thus enabling them to achieve tactical surprise at Fort Mackinac.[20]

The only military action on Wisconsin soil during the War of 1812 occurred in 1814 when Americans at St. Louis moved up the Mississippi and built Fort Shelby at Prairie du Chien. British Colonel Robert Dickson recognized that an American strong point at such a strategic location would undermine continued British control of the fur trade in Wisconsin and the upper Mississippi valley. Accordingly, he quickly organized a force of Indians, fur traders and a few British soldiers under the command of Lt. Col. Wm. McKay which compelled the American construction party commanded by Lt. Perkins to surrender Fort Shelby before the regular American garrison arrived.[21]

While Col. McKay's capture of Fort Shelby temporarily restored the British flag to all of Wisconsin, the Treaty of Ghent in 1815 required all British Canadians to leave Wisconsin. Captain Andrew Bulger, the last commandant of Fort McKay, lowered the Union Jack, burned the fort and embarked his garrison on the Fox-Wisconsin waterway for their voyage back to Canada.[22]

The Fox Valley 1816-1840

American defeats at Fort Mackinac, Fort Dearborn, Fort Shelby and the surrender of American General Hull's army at Detroit in the War of 1812 caused the U.S. War Department to establish and garrison a chain of frontier forts from the Canadian border to the Gulf of Mexico. It was hoped the forts would protect American frontier communities against future Indian attacks, aid in the establishment of American control of Wisconsin and block Canadian fur traders from using the Fox-Wisconsin and the upper Mississippi Rivers.

An early step in implementing the War Department's plan for frontier forts was the arrival of the American Third Infantry Regiment at Green Bay on August 7, 1816, and the subsequent construction of Fort Howard. When Col. Chambers and Third Infantrymen were ordered to Prairie du Chien in the spring of 1817 to rebuild and garrison a fort there, Fort Howard's second commanding officer was Major Zachary Taylor, the hero of Buena Vista and later the President of the United States. When Col. Chambers' Third Infantrymen passed up the Fox River in the spring of 1817 they were the first American military force to travel through the valley.[23]

Two years later in the summer of 1819, the Fifth Infantry Regiment under the command of Col. Henry Leavenworth traveled up the Fox, through Lakes Winnebago and Butte des Morts and up to the portage, in the process of being redeployed from Detroit to the western frontier. The Fifth Infantry garrisoned Forts Armstrong and Crawford, and built Fort Snelling, the northern anchor of the frontier fort system, at St. Paul, Minnesota. Captain Henry Whiting, an officer in Leavenworth's command, wrote a journal describing the Fifth Infantry's journey and sketched a scene at Neenah and Big Lake Butte des Morts and two of the "Grand Kakalin" portion of the Fox River rapids which are probably the oldest existing sketches by an American of scenes in the Fox Valley. Captain Whiting's report, including these watercolored sketches brought him a commendation from the Secretary of War, John C. Calhoun.[24]

In the summer of 1820, the Territorial Governor of Michigan, Lewis Cass, his secretary, James Duane Doty, later a Wisconsin Territorial governor. Henry Schoolcraft, famous Indian agent-author-anthropologist, Dr. Alexander Wolcott, expedition physician and a party of forty men passed down the valley bound for Green Bay and Detroit on the last leg of perhaps the most unusual canoe trip ever taken through this area. The Cass party were completing a 4,200 mile "Voyage of Inspection" through Michigan Territory which then included most of the present-day states of Minnesota and Wisconsin, as well as Michigan. The Cass expedition rode in three birch bark canoes each of which was 36 feet long, had a beam of seven feet, carried a mast and sail and was propelled by eight-man crews.[25]

By August of 1823 James Duane Doty had become the newly appointed Circuit Judge of western Michigan and had been married. Doty and his bride traveled up the valley on the Fox-Wisconsin to Prairie du Chien in August of 1823 to spend the winter and to hold the first session in Wisconsin of the Michigan Territorial Superior Court at Prairie du Chien in May, 1824.[26] In the fall of 1824, Doty convened his court at Green Bay and there built his first home in Wisconsin.

When a series of murders of Whites by Winnebago Indians in the vicinity of Prairie du Chien and La Crosse threatened to precipitate an Indian war in 1826-27, a detachment of more than 500 men under the command of Gen. Atkinson moved from Jefferson Barracks at St. Louis to Wisconsin by keel boat. Two hundred soldiers from Col. Snelling's garrison at Fort Snelling came down the Mississippi to Fort Crawford at Prairie du Chien. An additional force of soldiers, militia and Indians, under the command of Major Whistler from Fort Howard, marched up the Fox Valley to the Fox-Wisconsin portage and dug in on the hill east of the Fox River where Fort Winnebago was built in 1828.

The rapid concentration of American military power in the heart of the Winnebago country so stunned the Winnebago chiefs that they concluded fighting would be useless,, and assigned Chief Red Bird and an accomplice in the murders to sacrifice themselves to the Americans to preserve the Winnebago tribe. The Winnebagoes had helped to demonstrate that interlocking support from the frontier forts could not only safeguard the white man's frontier but had made effective Indian warfare in Wisconsin obsolete.[27] Unfortunately, Sauk Chief Black Hawk triggered a second demonstration of the futility of frontier forays by Indians when he precipitated the Black Hawk War in 1832.

When Sauk Chief Black Hawk led his "British Band" of nearly 2,000 Indians east across the Mississippi River in 1832, it was the final Sauk effort to reoccupy lands in the Rock River Valley of northwestern Illinois which the Sauks had owned for several generations.

Black Hawk was aware that Americans had built forts at Rock Island, Prairie du Chien, St. Paul and Green Bay since the War of 1812, but probably had no adequate understanding of the improved effectiveness of the American army despite the Winnebago tribe's humiliation by the Americans in the Red Bird Disturbance of 1828. Black Hawk's ignorance or bull-headedness was to cost his band the loss of nearly ninety percent of their number in about ninety days. The Sauk's stunning losses in 1832 made it clear to tribes in the upper Mississippi Valley that the advance of the white man's agricultural frontier could no longer be halted by Indian murders or gunfire. Perceptive tribal chiefs, i.e., Sauk Chief Keokuk and Menominee Chief Oshkosh, also concluded that tribesmen had no alternative to negotiating a final surrender of their tribal lands to the accelerating flood of land-hungry Americans.

During the Black Hawk War two companies of Menominee Indians were enlisted at Green Bay and commanded by Col. Samuel Stambaugh, the new Indian agent at Green Bay. Augustin Grignon of Butte des Morts was the captain of one of the Menominee companies; his lieutenants were his son, Charles, and his nephew, Robert. George Johnston, former sheriff of Brown County, was the captain of the second Menominee company; Johnston's lieutenants were William Powell whose farm was in the present-day town of Algoma, and James Boyd, son of the former Indian agent at Green Bay.[28]

The last traveler up the Fox Valley from the Black Hawk War was Chief Black Hawk himself. After captivity as a prisoner of war at Jefferson Barracks, Missouri and Fort Monroe, Virginia, Black Hawk was escorted back to Fort Armstrong and released to his detested tribal rival, Sauk Chief Keokuk. When Black Hawk traveled up the Fox Valley and west along the Wisconsin to the Mississippi, the Black Hawk War was finally over.[29]

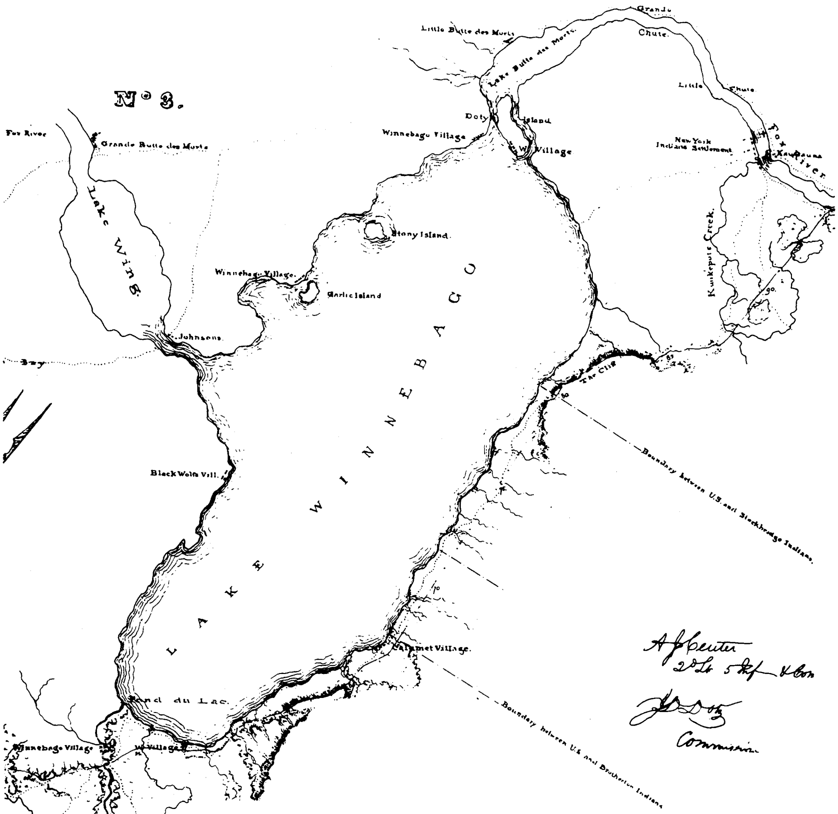
This chronicle of early Fox Valley events triggered by governmental action should include the survey and construction of the military road from Fort Howard to Prairie du Chien. In 1829, frontier promoters James Duane Doty of Menasha and Morgan L. Martin of Green Bay urged General Macomb in Washington, D.C. to use troops to open a road from the head of Lake Winnebago to Green Bay. Since it was politically more justifiable to build a road linking the frontier forts, in 1832 a party led by Lt. Alexander Center completed surveys and construction plans for a 234 mile military road from Fort Howard at Green Bay to Fort Winnebago at Portage and to Fort Crawford at Prairie du Chien (Fig. 2). Actual road construction began in the spring of 1835.

The section of the military road between Fort Crawford and Fort Winnebago was built by three companies of soldiers from Fort Crawford under the direction of Col. Zachary Taylor. Three companies from Fort Winnebago built the middle section of the road from Portage to Fond du Lac and the third section from Fond du Lac to Green Bay was built by three companies from Fort Howard.

The Fort Howard-Fort Crawford military road was a thirty foot wide lane through the timber. It was unpaved and in wet weather was virtually impassable for wagons. Grading was slight and so many high stumps were left standing that carriages and sleighs found travel difficult. It was not until the end of 1837 that the road was even nominally complete. Nevertheless, for many years the military road was the only overland route between Green Bay, Fond du Lac, Portage, Madison, the lead region and Prairie du Chien. Military troops and supplies passed over it frequently, and a growing stream of settlers increased the flow of traffic.[30]

In August, 1836, Henry Dodge, the newly appointed Territorial Governor of Wisconsin, crossed the Fox River at Algoma in present-day Oshkosh, paying a toll on a ferry belonging to James Knaggs. Governor Dodge was on his way down the Fox to negotiate the Treaty of Cedar Point by which the U.S. Government purchased 4,100,000 acres from the Menominee Indians on September 3, 1836 for $700,000. By this treaty the Menominees gave up title to all land in Wisconsin north of the Fox River and east of the Wolf.[31]

In the summer of 1837, troops commanded by General Henry Atkinson journeyed up the Fox Valley by the new mili-



2nd Lt. Alexander J. Center commanded an Army survey party in 1832 which mapped the Fox River in the process of looking for an appropriate location for a military wagon road between Forts Howard, Winnebago and Crawford. The Military Road was built in 1835-37, and ran along the east shore of Lake Winnebago.
Source: State Historical Society of Wis.

Fig. 2. Lieutenant Center's map of Lake Winnebago in 1833.

tary road from Fort Howard to Fort Winnebago and thence by keel boat to Fort Snelling. In 1839 a survey party of the U.S. Bureau of Topographical Engineers led by Captain Thomas J. Cram surveyed the potential of the Fox-Wisconsin rivers for steamboat navigation, concluding that the route could be made navigable (Fig. 3).[32]

A different kind of survey of the land area of the Fox Valley was conducted by contract surveyors working under the direction of the U.S. Surveyor General's office. Since enactment of the Northwest Ordinance of 1787, a rectangular system of mapping had been developed in which the government surveyors established boundary lines of Indian treaty lands, exterior township lines and then established subdivision lines including section, town, range and lot lines. Mapping of the Fox Valley south of the Fox River and Lake Butte des Morts was completed by 1834 and the map published by the Surveyor General's office in Cincinnati, October 23, 1835. The field work of mapping valley areas north of the Fox River and east of the Wolf seems to have still been in progress in January, 1839, but the completed map was published by the U.S. Surveyor's office at Dubuque, September 28, 1839. Once the maps were published, the

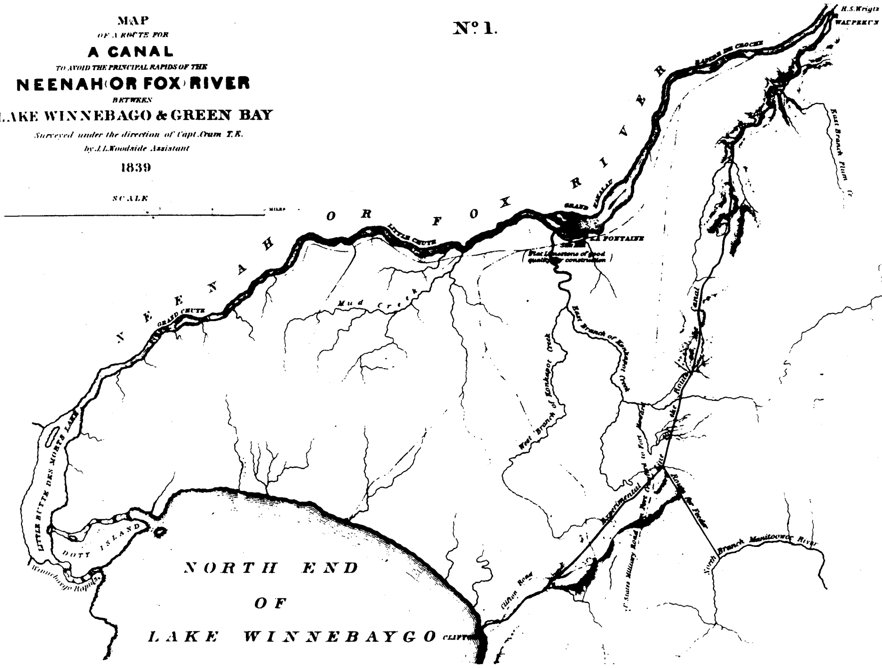


Fig. 3. U. S. Topographical Engineers Captain T. G. Cram led a party in 1839 which surveyed the potential for steamboat navigation of a canal from Lake Winnebago to Wrightstown. While this canal was never built, the cartographic skill of the engineers clearly had reached modern professional standards.

land offices could begin to throw the land open for public sale.[33]

County government first appeared in the Fox valley wilderness in 1818 when Governor Cass of Michigan Territory proclaimed a division into three counties of the territory's lands lying west of Lake Michigan and north to the Straits of Mackinac. Two of the counties, Brown and Crawford, comprehended the Fox-Wisconsin waterway. The county seat for Brown county was Green Bay and for Crawford County Prairie du Chien.

County affairs in Michigan Territory in 1818 and hence in the Fox River valley, were in the hands of a board of three county commissioners. Originally appointed by the territorial governor, by 1825 the county commissioners had become elective. The boards of county commissioners in Michigan Territory were replaced in 1827 by boards of county supervisors, one supervisor to be elected from each town.[34]

Direct participation by Fox valley citizens in the government of Michigan Territory began at Green Bay in 1821 when 42 votes were cast for Michigan territorial delegate to the U.S. Congress. More to the point, Fox valley and other Brown County voters in 1823 elected Robert Irwin of Green Bay representative to the Territorial Legislative Council from west of Lake Michigan.

The Fox valley was still a wilderness in 1823 but the tendency of significant historical events in the valley to be initiated by the agents of distant governments had now been largely reversed by the significant fact that the citizenry of the valley could express their needs to county, territorial and Congressional representatives or to judicial officers.

The Michigan Territorial Legislature

created Iowa County in 1830 and Milwaukee County in 1835 from the southern portions of Crawford and Brown counties, respectively. Thus when Wisconsin Territory began to function on July 3, 1836 there were four counties within the present day boundaries of Wisconsin, i.e. Brown, Milwaukee, Crawford and Iowa. The total white population of these counties in 1836 according to the territorial census was 11,683. Once Wisconsin legally became a territory in 1836 the Wisconsin Territorial Legislature created fifteen additional counties; those in or near the Fox valley were Calumet, Fond du Lac, Manitowoc, Sheboygan, Marquette and Portage. Three additional counties were created in 1840 including Winnebago in the Fox valley.[35]

The closing of the American Fur Company at Green Bay in 1844 was an historically symbolic requiem for Indians and fur trading in the Fox valley. Governmentally, the arrival of a new era was symbolized by the creation in the valley of the new counties of Fond du Lac, Winnebago and Calumet. Federal troops left the valley with the deactivation of Fort Howard in 1841. The arrival in the valley of the American agricultural frontier was marked by the first sizeable influx of settlers at Oshkosh in the summer of 1846, and by the platting of the villages of Neenah in 1847 and Menasha in 1849. Wisconsin Territory became the State of Wisconsin in 1848. Clearly, an era of more than two centuries of exploration, fur trading and the initiation of most major events in the Fox valley by governmental agents came to an end shortly after 1840.

Notes

[1] Thwaites, Reuben Gold, ed., *The Jesuit Relations and Allied Documents . . . Jesuit Missionaries in New France 1610-1791* (Cleveland, 1896-1901) 23: 1642-43. Jean Boisseau's map faces page 234.

[2] Charlevoix, Pierre F. X., *History of New France,* III (Paris, 1744), 178-179 (translation of John Gilmary Shea).

Severin, Timothy, *Explorers of the Mississippi* (New York, A. A. Knopf, 1968), 83-92.

[3] Charlevoix, *op. cit.,* V, Book 20, 257, 305-307.

S.H.S.W., *Collections,* 5:77-85.

Smith, Alice E., *The History of Wisconsin: From Exploration to Statehood,* I (Madison, Wis., State Historical Society of Wisconsin, 1973), 41.

[4] Wittry, Warren L., "The Bell Site: An Early Fox Village," *Wisconsin Archaeologist,* 44(1): 45-46.

[5] Charlevoix, *op. cit.,* 5:305.

[6] Hebberd, S. S., *History of Wisconsin Under the Dominion of France* (Madison, Wis., Midland Publishing Co., 1890), 121.

[7] Kellogg, Louise P., *The French Regime in Wisconsin and the Northwest* (Madison, Wis., State Historical Society of Wisconsin, 1925), 320-321; S.H.S.W., *Collections,* X, 47-53. The Chaussegros de Lery map in Kellogg, *op. cit.,* 314 seems to be the earliest existing map which shows substantial detail of the general vicinity of present-day Oshkosh, Lake Winnebago (Lac des Puants), Big Lake Butte des Morts (Petit Lac des Reynards) and the lower Fox River (Riviere des Reynards). The Fox fort east of the largest Fox village had been in existence, according to de Lery's map, since at least 1723 (Fort ou les Reynards sentient fortifie in 1723).

[8] Alvord, Clarence W. (ed.), *Centennial History of Illinois: The Illinois Country 1673-1818* (Springfield, Ill.: Illinois Centennial Commission, 1920), 163; Kellogg, *op. cit.,* 324.

Kellogg, L. P., "Fox Indians During the French Regime," S.H.S.W., *Proceedings,* 1907, 142-188.

[9] Kellogg, L. P., "Fox Indians . . ." *op. cit.,* 327; Alvord, *op. cit.,* 163-164.

[10] Kellogg, *op. cit.,* 329-330.

[11] Kellogg, *French Regime, op. cit.,* 329-331.

S.H.S.W., *Collections,* 17:210.

[12] Letter from Governor Beauharnois and Hocquart to the French Minister, Nov. 11, 1733 and Oct. 5, 1734, in S.H.S.W., *Collections,* 17:189-191, and 202-203.

[13] Kellogg, *op. cit.,* 331-332.

S.H.S.W., *Collections,* 17:188-191, 200-204; 3: 200; 8:207-208.

[14] Letter from Governor Beauharnois . . . to French Minister, *op. cit.,* 17:188-191.

[15] Kellogg, *op. cit.,* 334-335.

S.H.S.W., *Collections,* 17:221-229 and 216-221.

[16] Kellogg, *op. cit.,* 432, 436.

[17] "Narrative of Peter Pond," in Gates, C. M., *Five Fur Traders of the Northwest* (Minnesota Historical Society, 1965), 30-39.

S.H.S.W., *Collections,* 18:314-354.

[18] S.H.S.W., *Collections,* 2:165-170,174.

Kellogg, *op. cit.,* 191-192.

[19] Thwaites, Reuben Gold, *Wisconsin in Three Centuries,* II, 101, 140.

Kellogg, *op. cit.,* 282.

[20] Kellogg, *op. cit.,* 284.

[21] Kellogg, *op. cit.,* 315-319.

[22] Kellogg, *op. cit.,* 325.

[23] Prucha, Father Francis Paul, *Broadax and Bayonet* (Madison, Wis., S.H.S.W., 1953), 18-21; 54.

[24] *Captain Whiting's Journal, unpu*blished mss. in National Archives Microfilm Reel #1, No. 130, Rep. Book Pa397, in Fort Howard Consol. File 1819-1873.

[25] Schoolcraft, Henry R., *Summary Narrative of an Exploratory Expedition to the Sources of the Mississippi River in 1820 . . .* (Philadelphia: Lippincott, Grambo & Co., 1855), 190.

[26] Smith, *op. cit.,* 168.

[27] Prucha, *op. cit.,* 23-24. For a superb description of Red Bird at the moment of his surrender, see S.H.S.W., *Collections,* 5:178-204 in Col. Thomas McKenney, "The Winnebago War."

[28] Strong, Moses, "The Indian Wars of Wisconsin," S.H.S.W., *Collections,* 8:276.

[29] Hagen, William T., *Sac and Fox Indians* (Norman, Okla., University of Oklahoma Press, 1958), 200-201.

Smith, *op. cit.,* 133-150.

Nesbit, R. E., *Wisconsin: A History* (Madison, Wis., Univ. of Wisconsin Press, 1973), 95-100.

[30] Prucha, *op. cit.,* 135-144.

[31] Harney, Richard J., *History of Winnebago County* (Oshkosh: Allen and Hicks, 1880), 101.

[32] Source of Capt. Cram's map: U.S. Senate, 26th Congress, 1st Session (1840), Document 318, 16.

[33] Smith, *op. cit.,* 457.

[34] Wisconsin Historical Records Survey, *County Government in Wisconsin,* Vol. 1. 1942, 3-4.

[35] State of Wisconsin, *Wisconsin Blue Book, 1977,* (Madison, Wisconsin, 1977) 727.

PERCEPTION OF THE PRAIRIE IN A LETTER FROM PRAIRIEVILLE

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The arrival of a few Scots in 1840 marked the beginning of a sizable rural Scotch settlement that would develop in what was then Milwaukee County, but today Waukesha County, with Vernon Township as its center.[1] Within a short period of time, additional pioneers joined the vanguard to form a relatively dense settlement of Scots. Whereas a substantial number came directly from Scotland to the Wisconsin Territory, most of the initial settlers came from the general area of Livingston County, New York, where they or their families had settled earlier in the nineteenth century.

Included among the earliest arrivals in the Vernon area was the Robert Weir family,[2] which had reached Milwaukee by boat on October 26, 1841, and journeyed westward to Prairieville[3] the following day. Like so many others who eventually settled in Vernon, Weir had emigrated to New York from Scotland, where he was born in 1809.[4] Weir may have been attracted to the Prairieville area by a letter much like the one he sent back to New York encouraging friends to move west and join the growing settlement.

Weir's letter was addressed to William Fraser, postmaster of Fowlerville, New York, a small village in Livingston County.[5] The contents indicate, however, that it was an open letter intended for old friends; because of his position as postmaster, Fraser was being asked to pass on the news. Weir, in addressing the letter to Fraser, might have been epitomizing the popular stereotype of the frugal Scotsman. It has been suggested that "In order to save the 25 cent postage, Weir addressed the postmaster, . . . postmasters then enjoying the frank."[6] On the other hand, sending the letter to Fraser was necessitated, perhaps, by Weir's own strained financial resources resulting from a costly trip and subsequent investment in land. Although one cannot be sure that Weir was describing his personal financial situation, he wrote in the letter that "An empty purse and a new country maketh a hard beginning."

On the surface, Weir's letter might be considered typical of its genre. Many of the topics common in pioneer letters—the trip, family health, finances, general economic conditions and opportunities, prospects for agriculture, and perception of the new environment—are all covered in some depth. It is this last item, Weir's perception of the prairie, oak opening, and forest biotic communities, that is of particular interest and importance in this letter. The attitudes expressed and preserved in the personal papers of people like Weir have provided for a continuing re-evaluation of the importance of the prairie in the process of westward settlement.[7] Weir's pre-arrival perception of a section of the Milwaukee County prairie was somewhat at odds with his on-the-scene perception. Whereas Weir left New York intending to settle on a prairie farm, upon arriving he chose land[8] that, according to his own description, most likely would be classified as an oak opening. This change did not detract from Weir's enthusiasm for his new home. Weir's optimism remained high, although it was tempered by the reality of the frontier situation in which he found himself. His plan for success was altered somewhat (as is revealed in the letter) to fit his changing perception of the new surroundings, which were quite unlike those of his native Scotland or those of New York, his intermediate residence.

Weir's initial, positive perception of the Milwaukee County prairie he expected to encounter upon arrival was contrary to the general attitudes many historians have attributed to the so-called eastern woodland mentality. In his discussion of the settlement of the Lake Plains (which encompass a major portion of Wisconsin), Ray Allen Billington, for example, commented on the impressive beauty of the prairie, but he was quick to suggest that "Yet the prairie country was shunned by the first settlers, whose frontier technique was adjusted to a wooded country."[10] Moreover, he accounted for the early settlement of the wooded sections of southern Indiana and Illinois specifically by suggesting that "*adequate soil* [italics mine] and familiar vegetation" were available.[11] In a far more balanced treatment of the prairie-woodland controversy in Southeastern Wisconsin, Schafer felt obliged to point out that "The answer [to the question of whether to take a prairie or woodland farm] turned sometimes on men's belief in the superiority of forested land as land. . . ."[12] That Weir intended to take a prairie farm while he was still in New York indicates that he did not fit the supposed popular mold. Whatever his sources of information were about the physical fundament of a portion of old Milwaukee County, they did not allow him to conclude that prairie soil was "inadequate" or inherently less fertile than that of the East.

A change in Weir's on-the-scene perception is evident when he wrote that ". . . I do not think they [prairie farms] are as good for wheat as the [oak] openings or timber land. . . ." However, it does not seem reasonable to conclude that the change was prompted by any empirical evidence indicating the prairie soils were inferior; quite the opposite appears to have been the case. Later in the same paragraph where he compared the Genesee country with his new home, Weir was very explicit: ". . . the soil is better [in the Prairieville area], there is no mistake about it. . . ." Earlier in the letter Weir expressed satisfaction with his choice of land when he stated, "I think that I have got a good wheat farm."

One question remains: What motivated the change in perception then, if it was not the real or imagined low fertility of prairie soils? Throughout the letter, Weir's preoccupation with the forest resource was evident. He wrote of his desire to acquire timber land to complement this prairie farm; he bemoans the fact that "There is but little timber on it [the farm], say enough to fence it into 20 acre lots." Another reference to "trees [being] thinly scattered over" the farm suggests a dissatisfaction with the timber supply and is not a reflection of poor soil quality. This writer contends that Weir's perception is summarized well when he writes that ". . . it is hard to get a prairie farm and timber enough for the same." In other words, he valued the prairie soil but viewed the paucity of timber as a definite drawback.

Weir's actions support the contention. In the spring of 1842, he sold his land in section 12 and purchased 160 acres in section 1, about one mile north.[13] Apparently his desire to obtain some "first rate timber land" was realized in this transaction.[14] It is quite possible that included within his purchase was some of the desirable timber land to which he made reference in the letter.

It seems clear that Weir's perception and subsequent actions were not unique among settlers on those portions of the American frontier where the prairie was encountered. Mounting evidence suggests that early settlers did not shun the prairie because of assumed greater fertility of woodland soil. Studies centered in Iowa,[15] Illinois,[16] Texas,[17] and Michigan[18] have revealed, as John Fraser Hart has suggested, "that the pioneers, wherever possible, preferred to settle along the prairie—woodland edge, so that they might enjoy the advantages of both types of country."[19] The fertility of the prairie soil combined with the wood from forested areas used to build houses, barns, fences, and used to make fires for warmth and cooking offered an attractive inducement for settlement among pioneers like Weir.

In his letter that follows, Weir wrote forcefully in a style that ranges from folksy to simple eloquence. For clarity, punctuation and capitalization have been provided where they were absent in the original. The spelling and grammar have not been changed from the original, because they do not detract from a complete understanding of Weir's thoughts.

Mr. Wm. Fraser
Dear Sir:

According to promise I set down to give you a few lines. I hope you will excuse me in being so long in writing, as I sent word to you by Mr. Dn. [Duncan] Cameron[20] [of] Caledonia [New York] that we had got here safely. And I am happy to inform you that we are all in good health at present. And it may aford you comfort to know that we are in a healthy country blessed with a good appetite and plenty to satisfy the same. It may be that you have heard that we had a rough passage on the Las [lakes]. We were nine days on the water and part of the time it was very stormy. When when [sic] we came into Lake Huron we had a high head wind and a heavy sea, so much so that we had to turn round and go with the wind for sometime, and when we came into Lake Michigan we were again able to put round again and take shelter at an island and remain for one day. Yet we enjoyed ourselves as well as could be expected. We were on a first rate Boat, had a good Captain and a respectable set of hands, likewise a good Bar, and we were some[what] like Tom O'Shanter—we did not mind the storm a whistle. I did not get sea sick at all. My family did a little, yet stood it better than might be expected. We landed at Milwaukie on the 26th [of] Oct. and came to Prairieville [Waukesha] the 27th. James Wallace, James Begg [Jr.] and their families arrived at Prairieville on the 26th. James Begg [Sr.] and his [family] who came by land arrived on the 28th. Strange to think that we all started from home at different times to come such a distance, some by water and some by land and to arrive here in such rotation on the 26th, 27th and 28th. Prairieville is 18 miles west from Milwaukie and I think in a short time will be a great place for business. There is now a first rate flowering mill, one saw mill, one blacksmith's shop and plenty of business for three hands (James Wallace is employed in the same). There is a good waggonmaker's shop built last faull. There is two copper shops, three stores and one tavern, one drug store, one saddler, a number of shoemakers and tailors well employed there, one meeting house finished and two not finished, one stone Academy not finished inside, preachers without number, such as they are, and two or three Doctors but little employment for the same. Milwaukie will be a great place. She is in much want of a Harbor and has likewise been wanton for water power, but it is thought money will be granted this winter for a harbor and there is a damm across the Milwaukie river nearly finished, which is said will give her water power sufficient for one hundred run of stores. If a good harbor is got and good flowering mills built, the market here will be much better. When these things are done Milwaukie will be to this country as Rochester is to western N. [New] York. Wheat has been carried from here to Buffalo for 15 cents per bus. [bushel] but 18 pence [or] 2/ is the general price.[21] Wheat is worth at present from 70 to 75 cents, corn 2/9, oats 1/6, pork 2 dollars and 50 cents, beef about the same. Goods are but little higher here than they are in Fowlerville and plenty of everything to be got. Money is rather scarce, but it is known to be so in every new country. I think this will be fine wheat growing country although there is but little raised as yet for export. Farmers that have been here 4 or 5 years appear to have but little done by way of improvements. They say it is hard beginning. The fact is many come here poor and have nothing to begin with. An empty purse and a new country maketh a hard beginning. This country is settling very fast. I was much disappointed in finding the land so much taken up as it is. I looked round thinking to find land at government prices, [$1.25 per acre] but I could not find it good and in a convenient place, although I did not go more than 35 miles back from the Lake [Michigan]. The people say that more land has been taken since last spring than was taken in two years previous.

You may tell Neil McDugal[22] that I have bought a farm in his neighborhood. It is between his son-in-law[23] and the Milwaukie road.[24] My south line and his north line is the same on the west side of the cross road, or as it is called, the Rochester road,[25] and James Begg has bought on the west side of the said Rochester road. His south line and McDugal's north line is the same. James Wallace has bought John McIntyre's farm in the same neighborhood. I am nearly two miles west from him.[26] William Begg is thinking of buying Mr. Plumm's[27] farm in said neighborhood. It is going to be quite a Scotch settlement, and tell the Deacon[28] if he doth not come on to his land we will either sell it or burn it up, and tell him that I think there is Deacons enough where he is and we want him to be the old Deacon amongst us here, and tell him further that the best wheat that I have seen in the Ter. [Territory] was raised in that neighborhood. I think that I have got a good wheat farm. I bought 160 acres, and I intend to buy 40 acres more which joins said 160, which will make 200 acres for cultivation, and there is 80 acres of first rate timber land 1½ mile to the north which I was intending to take at gov't. price to keep as a timber lot, but it is thrown out of market at present, and I do not know if I can get it. If not, there is 60 acres equally as good timber and about the same distance from me which I can get for 3 Dollars per acre. My best respects to James Hamilton and not forgetting his Lady. Tell him that I think I have got as good a wheat farm as there is in Sugarburry [New York].[29] There is but little timber on it, say enough to fence it into 20 acre lots. Large trees [are] scattered thinly over it consisting of white oak, black oak, black walnut and some maple, and part of it is thickly grown over with hazel brush. There is a small log house on it and 8 acres broken up [and] 10 acres fenced. It will require three yoke of oxen to plough it the first time. Stone enough but not too many apparently.

When I left [New] York state I was fully in the belief that I would take a prairie farm. They are pleasant to the eye, but I do not think they are as good for wheat as the [oak] openings or the timber land, and it is hard to get a prairie farm and timber enough for the same. Water is likewise hard to be got on many of them. I think the land in this country is good in general, but I do not think the face of the country so handsome as the Genesee [New York] country is. It is more rolling or broken, but the soil is better, there is no mistake about it, and the healthiness of this country will speak loudly her praise. I have been in through Milwaukie, Racine and Walworth counties, and I have not seen man, woman or child sick.

Give my respects to all enquiring friends and acqus. [acquaintances]: Edward Craig the first time you see him, Js. Hamilton, Jn. Hamiltons, Rt. Wallance, An. Frrasers, As. McBean, Ts. Howie, all the old women about Fowlerville and espec. in Sugarburry and write to me as soon as this comes to hand.

If any letters come from Scotland send them to me. Direct [them] to me, Rt. Weir, Prairieville Post Office, Milwaukie County, Wisconsin Territory.

Robt. Weir

Dec. 27, 1841

NOTATIONS

[1] A brief history of the settlement is the focus of Edward C. Wicklein, *The Scots of Vernon and Adjacent Townships, Waukesha County, Wisconsin* (Waukesha, 1974). Wicklein reprints a copy of the letter (pp. 28-29) that is taken from a transcribed copy of the original, which contains errors and omissions. For a description of the contents and availability of this work see "Wisconsin History Checklist," *Wisconsin Magazine of History,* 57:326 (Summer, 1974).

[2] At the time of arrival, the family consisted of Robert and his wife Mary, both 30 years of age, and young daughters Margaret and Mary Jane, 5 and 2 years of age, respectively.

[3] The present City of Waukesha was formerly known as Prairieville. When Waukesha County was separated from Milwaukee County in 1846—to create a separate political unit—the name change took place. Prior to being called Prairieville, the little settlement was known as Prairie Village for a short period of time.

[4] It is difficult to determine the date of Weir's arrival in the United States. A Declaration of Intention to Become a Citizen of the United States in the name of Robert Weir is not on file in either Livingston County, New York (personal communication from Miss Anna Patchett, County Historian, Livingston County, May 29, 1975) nor Waukesha County, Wisconsin. It is certain that Weir was in New York by 1832 as his name is included on a list of members of the United Presbyterian Church of York for that date (Mary R. Root, *History of the Town of York, Livingston County, New York* (Caledonia, 1940), 99).

[5] The original Weir letter is in an unclassified collection of the Waukesha County Historical Museum, Waukesha, Wisconsin.

[6] John G. Gregory, ed., *Southeastern Wisconsin: A History of Old Milwaukee County,* Vol. II (Chicago, 1932), 965. Excerpts of the Weir letter are provided on pages 965 and 966. However, errors are apparent when the excerpts are compared with the original letter.

[7] An effective use is made of letters and other personal papers in this regard by Douglas R. McManis, *The Initial Evaluation and Utilization of the Illinois Prairies, 1815-1840* (Chicago, 1964).

[8] A deed dated December 11, 1841 records Weir's purchase of the NW1/4 of Sec. 12, T. 5 N., R. 19 E., from John C. Snover for a sum of $450, or just over $2.80 per acre, which was more than twice the price of government land.

[9] A map entitled Presettlement Vegetation of Waukesha County, 1836, prepared by Marlin Johnson and Jerry Schwarzmeir (1973) from the Public Land Survey Notes and Plats shows this to be the case. In addition, a portion of the land that became Weir's farm was reported to have been burned over shortly before the surveyor reached the area and appears on Johnson and Schwarzmeir's map as "burned."

[10] Ray Allen Billington, *Westward Expansion* (New York, 1949), 294.

[11] *Ibid.*

[12] Joseph Schafer, *Four Wisconsin Counties: Prairie and Forest* (Madison, 1927), 107. In an explanatory footnote for this point, Schafer adds: "Many Yankees had this belief until the virtues of the prairie lands had been thoroughly tested."

[13] Weir sold his farm for $650.00 and purchased the SW1/4, Sec. 1, T. 5 N., R. 13 E. from Caleb Nanscawen for the sum of $775.00.

[14] In addition to wanting timber for use on the farm, it seems reasonable to suggest that Weir's desire for acquiring good timberland was motivated by his intent to engage in the sawmill business in the very near future. "Mr. Robert Weir . . . built a saw-mill at Big Bend, which ran by steam. At this mill, most of the plank used in constructing the Muk[wonago] and Mil[waukee] road was sawed" (*The History of Waukesha County, Wisconsin* (Chicago, 1880), 791). The mill was built between December 27, 1841, the date of Weir's letter, and 1848, the date of incorporation of the road (*Ibid.*, 387).

[15] Leslie Hewes, "Some Features of Early Woodland and Prairie Settlement in a Central Iowa County," *Annals,* Association of American Geographers, 40:40-57 (March, 1950).

[16] McManis, *The Initial Evaluation and Utilization of The Illinois Prairies, 1815-1840.*

[17] Terry G. Jordan, "Pioneer Evaluation of Vegetation in Frontier Texas," *Southwestern Historical Quarterly,* 76:233-54 (January, 1973).

[18] Bernard C. Peters, "Pioneer Evaluation of the Kalamazoo County Landscape," *Michigan Academician,* 3:15-25 (Fall, 1970).

[19] John Fraser Hart, *The Look of the Land* (Englewood Cliffs, 1975), 7-8.

[20] Like Weir, Cameron reached Vernon Township in October, 1841, in the company of three other bachelors. Apparently Cameron returned to New York shortly thereafter, as did Donald

Stewert (*Waukesha Freeman,* September 3, 1910), a fellow traveller, to report in person to relatives on the opportunities in the Wisconsin Territory. In subsequent years a number of Cameron's relatives settled in Vernon Township.

[21] The following monetary equivalents apply to the prices quoted:

One pence = 1 cent or 10/125 shillings

One shilling = 12½ cents

[22] The reference here is obviously to Neil McDougal, who has been credited with being the founder of the Scotch settlement in Vernon (see the *Waukesha Freeman,* September 3, 1910 and September 16, 1943). McDougal was a wealthy New York farmer who came west to invest in real estate. In 1840 he purchased a number of tracts of land, and then returned to New York where he was at the time Weir's letter arrived with the message for him.

[23] McDougal's daughter Ellen was married to Findley Fraser, who owned the E1/2, SW1/4, Sec. 12, which, in part, was adjacent on the south to Weir's property.

[24] Reference here is to the Milwaukee-Janesville (via Mukwonago) road, which passed through section 1 about a half mile north of Weir's property. Presently this route is designated CTH ES (formerly STH 15) or National Avenue. For a map of territorial roads in Waukesha County, see: Southeastern Wisconsin Regional Planning Commission, *A Jurisdictional Highway System Plan for Waukesha County,* Planning Report No. 18, (Waukesha, 1975), 19.

[25] The road mentioned here, with a north-south trend, passed through the middle of section 12 and in section 13 angled to the west and south where it entered Big Bend, and then it continued in a southerly direction, closely paralleling present-day CTH F, to Rochester in Racine County.

[26] The record does not indicate such a purchase. A Hugh (not John) McIntyre owned the S1/2, NW1/4 of Sec. 5, T. 5 N., R. 20 E., the Township of New Berlin, which is immediately east of Vernon. Weir's property would have been "nearly two miles west from" the McIntyre land.

[27] Apparently Weir is referring to Joseph A. Plumb here. There are no Plumms listed as being land owners in the vicinity at this time.

[28] The reference to "the Deacon" in the broader context of the idea being developed coupled with the fact that Neil McDougal was an elder in the United Presbyterian Church of York, New York, suggests that Weir is still referring to McDougal here, as he was at the outset of this paragraph.

[29] The common spelling is Sugarbury. This small village was located in the Town of York across the Genesee River from Fowlerville, which was in the Town of Avon.

THE PHYCOPERIPHYTON COMMUNITY OF THE LOWER BLACK RIVER, WISCONSIN

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Abstract

Phycoperiphyton taxonomic composition was determined from materials gathered from the Black River, La Crosse County, Wisconsin. Phycoperiphyton samples were collected from two stations at each of four sites during the open water season, April through November 1976.

Fifty-six genera and 205 species were found. The phycoperiphyton community was dominated by members of the class Bacillariophyceae (ca. 98% of the total community). *Achnanthes lanceolata,* was the dominant species during spring months. *Melosira varians* dominated by mid-June and was succeeded by *Cocconeis placentula euglypta* during July through late September. *Navicula cryptocephala* followed in the autumn, and during the final sampling period in November *Diatoma vulgare* was the dominant species.

INTRODUCTION

The Black River is a tributary of the Mississippi River with the confluence located 11.5 km (7 mi) north of La Crosse, Wisconsin. From its headwaters, located approximately 267 km (160 mi) NNE in Taylor County, to the Mississippi drains 5490 km^2 (2129 m^2). This investigation, performed during April through November 1976, was undertaken to determine the taxonomic composition of the phycoperiphyton community and to establish the density and relative density of the several species.

DESCRIPTION OF THE STUDY AREA

The southern portion of the Black River, located between. lat. 43° 57″ to 44° 03″ and long. 91° 12″ to 91° 16″, forms the northern boundary of sections 1 and 2 and the western boundary of sections 10, 16, 21, and 27 of Holland Township, La Crosse County, T. 18 N., R. 8 W. (Fig. 1). United States Geological Station 05382000 is located about 50 m upstream from the first set of sampling stations used in this study. The study area covered 11 km (6.6 mi) of river which in the study area meanders through an area known as the Black River Bottoms. Agricultural crops and a few pastures are found along the Trempealeau County side of the river. Swimming, canoeing, and fishing are popular recreational activities on the Black River.

Two stations were established at each of four sites. At each site, one station was placed where the current velocity was greatest, and a second station where current velocity was least. Direct sunlight was also considered in station location because it greatly affects phycoperiphyton distribution (Table 1). United States Highway 53 spans the Black River at a crossing known as Hunter's Bridge, 3.5 km (2 mi) southeast of Galesville, Wisconsin. This bridge serves as a reference point for site locations (Fig. 1). Stations have the designation of N or S which indicate that the locations were nearer to the northern (N) or southern (S) bank of the river.

MATERIALS AND METHODS

Phycoperiphyton samplers were constructed from plastic slide boxes (Strenski, 1977). Two samplers, each containing eight evenly spaced glass slides, were set at each

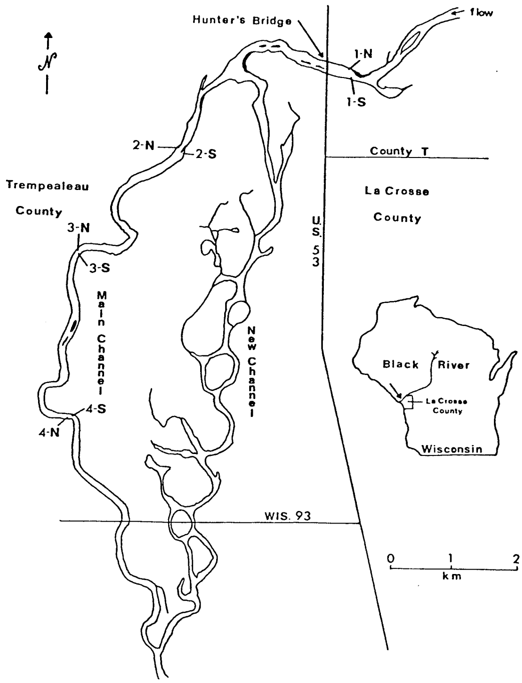

Fig. 1. Black River between Trempealeau and LaCrosse counties. Locations of paired sampling stations are indicated as 1-N and 1-S, etc.

TABLE 1. Direct sunlight estimates, mean and range values for current velocity (m/sec), and depth (m) at each station in the Black River, 10 April through 20 November 1976.

Station	*Direct[a] Sunlight*	*Current Velocity*	*Depth*
1-N	1	0.01	0.27
		(<0.01-0.03)	(0.15-0.50)
1-S	3	0.14	0.70
		(0.03-0.23)	(0.35-1.05)
2-N	2	0.23	0.42
		(0.10-0.36)	(0.20-0.70)
2-S	2	0.01	0.91
		(<0.01-0.06)	(0.50-1.35)
3-N	1	0.28	0.70
		(0.04-0.39)	(0.20-1.50)
3-S	3	0.26	0.44
		(0.11-0.50)	(0.15-1.00)
4-N	1	0.16	0.26
		(<0.01-0.42)	(0.07-0.55)
4-S	2	0.30	1.17
		(0.21-0.48)	(0.85-1.75)

[a] Direct Sunlight = 1—Direct sunlight at least until early evening.
2—6 to 8 hr of direct sunlight daily.
3—Less than 3 hr of direct sunlight daily.

station. Slides were inserted vertically to avoid sedimentation. Duration of slide exposure ranged from 14 days during the spring and summer, to 18-21 days during the autumn.

Material for identification was scraped from the glass slides into a solution of "M[3]" preservative (APHA 1975). Diatoms were cleared and permanently mounted in Hyrax® prior to analysis (APHA 1975). The phycoperiphyton was identified to the lowest taxonomic level possible using bright-field microscopy. Taxonomic keys used included those of; Bourrelly (1968), Cleve-Euler (1955), Hansmann (1973), Hohn and Hellerman (1963), Huber-Pestalozzi (1942), Hustedt (1930a, 1930b), Patrick and Reimer (1966), Prescott (1962), Smith (1950), Tiffany and Britton (1952), and Weber (1971).

A standard Palmer-Maloney cell (Palmer and Maloney 1954) was used to determine density of all living cells (diatoms and non-diatoms) and for the identification of non-diatoms. At least 500 organisms per counting cell were tallied. The relative densities of each taxa within the diatom community were estimated by the species proportional count method (APHA 1975). A minimum of 500 cells were counted from each Hyrax® mount.

RESULTS AND DISCUSSION

The phycoperiphyton in the Black River represented four classes of algae: Bacillariophyceae (diatoms), Chlorophyceae (green algae), Dinophyceae (dinoflagellates), and Myxophyceae (blue-green algae). Fifty-six genera and 205 species were identified; twenty-nine of the 205 species were further identified to include 75 varieties.

Members of the class Bacillariophyceae were the major dominants. This class was represented by 192 species in 35 genera and accounted for approximately 98% of the phycoperiphyton community. Diatoms from 28 species belonging primarily to the genera *Fragilaria, Synedra, Achanthes, Navicula,* and *Pinnularia* were further identified to variety level. Seasonally dominant taxa included *Achnanthes lanceolata, Melosira varians, Cocconeis placentula euglypta, Navicula cryptocephala,* and *Diatoma vulgare.* These five taxa comprised about 44% of the phycoperiphyton. Two species, *Navicula cryptocephala* and *Nitzschia palea,* occurred in each sample while 15 taxa appeared in at least 93.9% of the samples. *Navicula cryptocephala* ranked first in relative density (16.72%). *Cocconeis placentula euglypta* and *Melosira varians* ranked second and third with 12.55% and 8.24%, respectively.

The Chlorophyceae were represented by 20 genera but the group was not a major community component. This class contributed only 2.24% of the algae encountered but representatives of Chlorophyceae were found in 85.7% of the samples. The most frequently encountered green algae were *Scenedesmus quadricauda, Pediastrum duplex,* and *Scenedesmus dimorphus,* which were found in 71.4%, 43.9%, and 42.9% of the samples, respectively.

Single species of *Merismopedia* and of *Oscillatoria* represented the class Myxophyceae; each occurred in early autumn at different stations.

Ceratium hirundinella was the sole representative of the class Dinophyceae and was noted only once.

The rank of the common phycoperiphyton taxa according to mean relative density (% of the total community) was determined (Table 2). Common taxa are those taxa with a relative density of $\geq 1\%$. Eighteen taxa were specified as common. *Navicula cryptocephala* (16.72%), *Cocconeis placentula euglypta* (12.55%), and *Melosira varians* (8.24%) ranked first through third, respectively. These were followed by *Nitzschia palea* (4.44%) and *Navicula exigua capitata* (3.91%). Six taxa had relative densities between 3.72% and 2.74%, while seven other taxa each comprised be-

TABLE 2. Common phycoperiphyton taxa in the Black River ranked according to mean relative density. Ranking is based on samples from all stations, 10 April through 20 November 1976.

Rank	*Taxon*	*Relative Density (%) (mean and range)*
1	*Navicula cryptocephala*	16.72 (0.36-60.78)
2	*Cocconeis placentula euglypta*	12.55 (0.00-56.02)
3	*Melosira varians*	8.24 (0.00-54.43)
4	*Nitzschia palea*	4.44 (0.37-12.38)
5	*Navicula exigua capitata*	3.91 (0.00-14.26)
6	*Cocconeis placentula*	3.71 (0.00-18.55)
7	*Achnanthes lanceolata*	3.67 (0.00-34.55)
8	*Melosira italica tennuissima*	2.92 (0.00-12.35)
9	*Diatoma vulgare*	2.87 (0.00-66.60)
10	*Cyclotella stelligera*	2.85 (0.00-14.38)
11	*Cyclotella atomus*	2.74 (0.00-15.30)
12	*Achnanthes lanceolata rostrata*	2.31 (0.00-12.05)
13	*Gomphonema angustatum producta*	2.07 (0.00-29.55)
14	*Melosira italica*	1.56 (0.00-19.93)
15	*Synedra ulna oxyrhynchus*	1.54 (0.00-14.31)
16	*Nitzschia linearis*	1.40 (0.00-10.05)
17	*Navicula viridula*	1.24 (0.00-9.37)
18	*Navicula hungarica captitata*	1.19 (0.00-7.32)

TABLE 3. Common phycoperiphyton taxa in the Black River ranked according to frequency of occurrence (%). Ranking is based on samples from all stations, 10 April through 20 November 1976.

Rank	Taxon	Frequency of Occurrence (%)	Rank	Taxon	Frequency of Occurrence (%)
1	*Navicula cryptocephala*	100.0	27	*Melosira italica tennuissima*	72.4
	Nitzschia palea	100.0	28	*Achnanthes delicatula*	71.4
3	*Cocconeis placentula*	99.0		*Cymatopleura solea*	71.4
	Navicula exigua capitata	99.0		*Cymbella tumida*	71.4
5	*Achnanthes lanceolata rostrata*	98.0		*Scenedesmus quadricauda*	71.4
	Cocconeis placentula euglypta	98.0	32	*Navicula cuspidata*	69.4
	Melosira varians	98.0	33	*Navicula pupula*	68.4
8	*Achnanthes lanceolata*	96.9	34	*Navicula Bremeyeri*	67.3
	Cyclotella stelligera	96.9	35	*Cocconeis pediculus*	66.3
	Navicula hungarica capitata	96.9	36	*Diatoma vulgare*	63.3
11	*Melosira italica*	95.9	37	*Fragilaria pinnata*	62.2
	Nitzschia linearis	95.9	38	*Synedra rumpens*	61.2
13	*Cyclotella meneghiniana*	93.9	39	*Gomphonema angustatum*	60.2
	Gomphonema angustatum producta	93.9	40	*Fragilaria construens*	58.2
	Synedra ulna	93.9		*Fragilaria leptostauron rhomboides*	58.2
16	*Amphora ovalis*	89.8	40	*Navicula hungarica*	58.2
17	*Surirella tenera*	84.7	43	*Navicula tripunctata*	56.1
18	*Gyrosigma kutzingii*	81.6	44	*Cymbella ventricosa*	55.1
	Navicula viridula	81.6		*Tabellaria fenestrata*	55.1
20	*Opephora martyii*	80.6	46	*Cymbella naviculiformis*	54.1
21	*Achnanthes detha*	78.6		*Surirella ovata*	54.1
	Nitzschia amphibia	78.6	48	*Achnanthes exigua heterovalvata*	53.1
23	*Epithemia turgida*	76.5		*Caloneis lewisii*	53.1
	Stauroneis crucicula	76.5		*Surirella angustatum*	53.1
25	*Cyclotella atomus*	74.5	51	*Navicula elginensis*	52.0
26	*Rhiocophenia curvata*	73.5	52	*Eunotia lunaris*	51.0

tween 2.31% and 1.19% of the total community.

Common taxa were ranked by frequency of occurrence (Table 3). Frequency of occurrence is defined as the percentage of samples within which a taxon was found. Common denotes those taxa whose frequency of occurrence was at least 50%. This ranking included only one non-diatom taxon, *Scenedesmus quadricauda*. It ranked twenty-eighth with three diatom taxa. Several taxa including *Cyclotella meneghiniana* (frequency 93.9%), *Synedra ulna* (93.9%), *Amphora ovalis* (89.8%), *Surirella tenera* (84.7%), *Gyrosigma kutzingii* (81.6%), and *Opephora martyii* (80.6%) ranked in the top twenty but were never abundant in any sample. Only 52 of the 254 taxa occurring in the Black River had a frequency of occurrence $\geq 51\%$.

The algal density (cells/m^2) was calculated at each station. Stations which were heavily shaded, e.g. 3-S and 1-S which averaged about 1.70×10^9 cells/m^2, had phycoperiphyton communities with the lowest densities. This contrasted with 4-N (no shade) and 3-N (shaded only in the evening) where densities were about 3.00 X10^9 cells/m^2 (Fig. 2). Direct sunlight affected the density at each station and was categorized into three groups: those exposed to direct sunlight at least until evening (1-N, 3-N, 4-N), those exposed to 6 to 8 hr of direct sunlight (2-N, 2-S, 4-S), and those exposed to less than 3 hr of direct sunlight (1-S and 3-S). The "Student's" t-distribution was used to examine the effect of direct sunlight. Algal communities at stations with direct sunlight until evening had significantly greater densities than those at stations receiving less than 3 hr of direct sunlight ($P < 0.001$). Similarly, densities at stations with 6 to 8 hr of direct sunlight had significantly greater densities than those receiving less than 3 hr of direct sunlight ($P = 0.012$).

Sampling began during April when the high water resulting from the spring thaw began to subside. Low densities were found during April and May (8.8×10^8 cells/m^2). This may have resulted from the high spring discharge scouring the glass substrate. A spring maximum of 3.34×10^9 cells/m^2 was noted during early June; however, the greatest density occurred in early autumn when 3.47×10^9 cells/m^2 were observed. The lowest density (7.0×10^8 cells) was found during the final sampling period in November (Fig. 3).

Five species reached dominance during the study. Early in the season, from April to mid June, *Achnanthes lanceolata* was the dominant species. Its highest relative density was observed from 19 May through 2 June when it accounted for 21.00% of the total community. It remained common until 12 October when it comprised <1% of the total community. During its dominance, other common taxa included *Gomphonema angustatum producta, Achnanthes lanceolata rostrata, Nitzschia palea, Navicula cryptocephala* and *Achnanthes lanceolata ventricosa* (in order of decreasing relative density). Peak density of *Achnanthes lanceolata* (4.3×10^8 cells/m^2) occurred after *Melosira varians* became dominant (Fig. 4). At heavily shaded stations (1-S and 3-S) *Achnanthes lanceolata* had a relative density of 13%, while at stations with little or no shade (1-N and 4-N) this species had a relative density of about 18%.

Melosira varians dominated the community by mid-June. It attained a peak relative density of 34.14% and an average of 27% during the period 16 through 30 June. This was the only species that also exhibited a fall peak, reaching a value of 13.17% during the final sampling period. It remained a common taxon during each sampling period. Its relative density fell to approximately 1.50% during August and September. Peak density 16 through 30 June

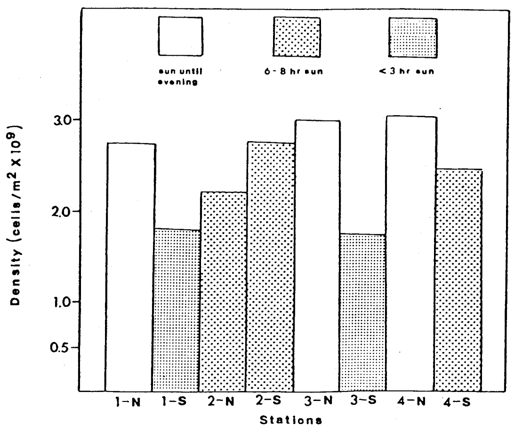

Fig. 2. Mean density of phycoperiphyton with respect to direct daily sunlight at each sampling station in the Black River, 10 April through 20 November 1976.

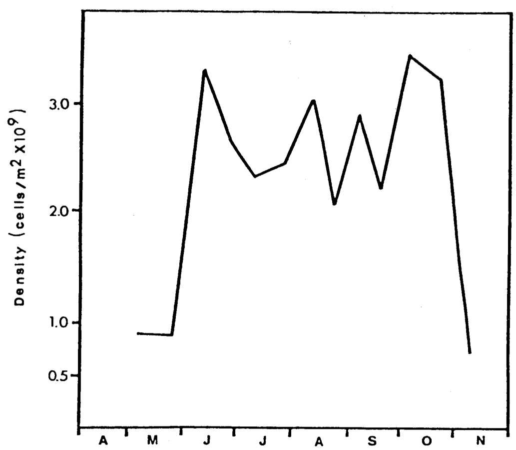

Fig. 3. Seasonal mean density of phycoperiphyton in the Black River, 10 April through 20 November 1976.

was 8.2×10^8 cells/m². A fall peak of 4.0 $\times 10^8$ cells was observed during 12 October through 2 November (Fig. 4), Smith (1950) documented this genus as the most commonly encountered of all freshwater Centrales. He further stated that *Melosira varians* may dominate during the early spring and late fall months. This species was also one of the two principal species found during October and November on the Ohio River (Weber and Raschke 1970). In the Black River the distribution of this species appeared to be relatively unaffected by direct sunlight. Relative density of *Melosira varians* at well-shaded stations differed from unshaded stations by only 3%. For example, during the period 2 June through 14 July relative density at 1-N and 4-N (no shade) was 24% while 1-S and 3-S (well-shaded was 21% for this species. Other common taxa occurring while *Melosira varians* dominated were *Navicula cryptocephala, Cocconeis placentula euglypta, Achanthes lanceolata,* and *Nitzschia palea* and *Navicula exigua capitata.*

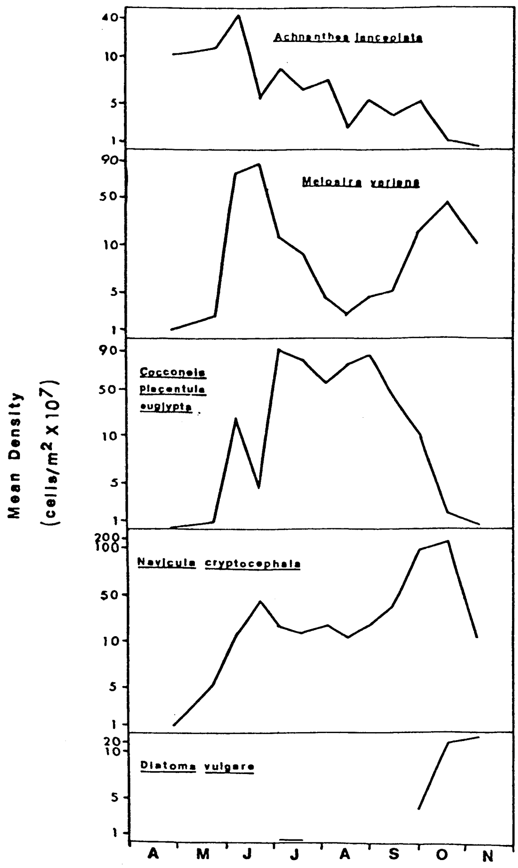

Fig. 4. Seasonal mean density of the five dominant phycoperiphyton taxa in the Black River, 10 April through 20 November 1976.

During July, August, and much of September, the dominant taxon was *Cocconeis placentula euglypta.* During that time this taxon ranged in relative density from 19.41% to 39.53% (14 thru 28 July). In contrast, *Achnanthes lanceolata* and *Melosira varians* were found in rather uniform relative densities while they were dominant. *Cocconeis placentula* was also a common taxon at this time. Massey (unpublished data) found this species and several varieties dominant in Pool 8 of the Mississippi River during midsummer. Weber and Raschke (1970) reported it as dominant in the Kalmath River, Oregon, during August. From 30 June through 22 September shading appeared to inhibit growth of this species. A relative density of about 37% was noted at stations 1-N and 4-N. During the same period the relative density at stations 1-S and 3-S only about 18%. A peak density of 9.2×10^8 cells/m² was noted during the sampling period 14 through 28 July (Fig. 4). *Navicula cryptocephala, Cocconeis placentula, Navicula exigua capitata, Nitzschia pales* and *Cyclotella stelligera* were also common throughout the summer months.

A shift in dominance to *Navicula cryptocephala* occurred during the autumn. This species was found only as a trace during the extended first period (10 April through 19 May), but comprised at least 5.24% of the algal community and was common throughout the remainder of the study. It attained its peak relative density of 53.27%, from 12 October through 2 November. At the same time it reached a peak density of 1.76

$\times$ 10^9 cells/m^2 (Fig. 4). This was the only taxon to yield a density greater than 10^9 cells/m^2 during any one sampling period and it was found in all samples. A variety of *Navicula cryptocephala* was reported by Bahls (1971) as a dominant species in the Upper East Gallatin River, Montana and was found in all samples collected from natural substrates. In the Black River, direct sunlight did not appear to significantly affect its relative density. Heavily shaded stations had 28% and essentially unshaded stations 29% from 8 September through 2 November. Taxa also common at this time were *Melosira varians, Synedra ulna oxyrhynchus, Nitzschia palea, Nitzschia linearis,* and *Diatoma vulgare.*

Diatoma vulgare appeared only in small amounts throughout most of the season; however, it became the dominant alga during the cooler autumn months, comprising 32.3% of the community. This taxon was reported by Blum (1957) in the Saline River, Michigan, as characteristic of the fall and winter diatom flora in unpolluted waters. Drum (1964) also found it most abundant during October and November in the Des Moines River, Iowa. Low relative densities were observed in the early sampling periods of the study, thus suggesting that it had been present throughout the winter months. Apparently direct sunlight was not a significant factor affecting distribution. Its relative density at station 3-S during the final period was 66.60%. This was the greatest dominance exhibited by any taxon during this study. A density of 2.4×10^8 cells/m^2 was recorded at this time. Other common taxa during this time included *Melosira varians, Synedra ulna oxyrhynchus, Nitzschia palea,* and *Navicula exigua capitata.*

Diversity indices were calculated for each sample both spatially and seasonally using the Shannon-Wiener (1963) index which ranged from 3.45 (4-S) to 4.19 (1-S) over the eight stations. Shading appeared to have a marked influence on diversity. Stations with less than 3 hr of direct sunlight daily had significantly greater diversities than stations that received direct sunlight until the evening ($P = 0.014$). Those stations which received less than 3 hr of direct sunlight also had significantly greater diversity than stations with 6 to 8 hr ($P = 0.034$). High mean diversity (>4.36) was observed during the early sampling periods (10 April through 2 June). Seasonal changes were most significant in the autumn when the mean diversity was reduced from 3.93 (July through mid-October) to 2.95 (for the remainder of the study). The overall seasonal mean diversity was 3.89.

Lloyd and Ghelardi proposed the term "equitability" to compare the observed mean diversity with the maximum possible diversity (EPA 1973). The normal range is 0 to 1. In the Black River this index ranged from 0.28 (4-N) to 0.46 (1-S) with respect to spatial distribution, with an overall mean of 0.36. Seasonal changes ranged from 0.19 (12 October through 2 November) to 0.55 (19 May through 2 June), with an overall mean of 0.33.

Current velocity is also a critical factor affecting the distribution of algae. Odum (1956) implied that the depleted life requirements needed by the algal flora were renewed and the accumulated by-products were removed by the water flowing over the organisms. Whitford (1960) stated that swift currents rapidly remove the somewhat impoverished water around a community and replenish it with fresh nutrient-rich water. Experiments conducted by Whitford and Schumacher (1961) demonstrated high rates of respiration and phosphorous uptake in algal cultures when exposed to currents of 0.15 m/sec as compared to still water. McIntire (1966) investigated the structure of two laboratory stream periphyton communities in which the currents were very slight in one stream and moderate (comparable to the swifter currents at stations in this study) in the other. He found that species composition of the two laboratory stream periphyton communities were approximately the same but that the relative densities differed significantly. This was also observed in the Black River with *Achnanthes lanceolata* which had relative densities of 11% (slow) and 17% (fast). *Melosira varians* showed relative densities of 17% (slow) and 22% (fast), while *Cocconeis placentula euglypta* had 27% (slow) and 33% (fast). *Navicula cryptocephala* with relative densities of 24% (slow) and 28% (fast), showed the smallest difference. *Diatoma vulgare* was markedly affected with 11% in slow currents in contrast to 24% in fast currents.

In a review of 165 studies, Palmer (1969) listed 80 of the most tolerant species of algae with respect to organic pollution. Included in his list were greens, bluegreens, diatoms, and flagellates. Twenty-three species that appeared on Palmer's list were identified in the Black River; however, only five were noteworthy. These species were (Palmer's rank in parenthesis) *Nitzschia palea* (2), *Melosira varians* (13), *Navicula cryptocephala* (17), *Diatoma vulgare* (40), and *Cocconeis placentula euglyypta* (58). *Nitzschia palea* was a commonly occurring species; however, in the Black River it never attained a position of dominance and always appeared in rather uniform relative densities. The remaining four species appeared in significant quantities; however, their presence was related to seasonal changes and apparently not to organic pollution.

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PRELIMINARY REPORTS ON THE FLORA OF WISCONSIN NO. 67. VERBENACEAE—THE VERVAIN FAMILY

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Abstract

The Verbenaceae, a huge, tropical plant family, is represented in Wisconsin by the genera *Verbena,* with five native and three cultivated species, and six hybrids, and *Phyla,* with one species. Wisconsin distribution maps plotted from herbarium specimens show the ranges of the above taxa. Dichotomous keys to genera and species, and descriptions, geographic range, ecology, phenology, and chromosome number for each species are given.

INTRODUCTION

The Verbenaceae, a large, primarily tropical family, is relatively poorly represented in Wisconsin, with only two genera and 15 taxa, including six native species, their six hybrids, as well as three garden ornamentals which are rare escapes. Of these, the taller, common, often weedy *Verbena hastata,* Blue Vervain, *V. urticifolia,* White Vervain, and *V. stricta,* Hoary Vervain are familiar plants.

The Verbenaceae present no special problems to floristic workers despite the many hybrids, largely because Harold N. Moldenke, formerly of the New York Botanical Garden, has monographed the Verbenaceae and published treatments in many regional floras. Some 70 publications on *Verbena* alone by this prolific author have appeared in *Phytologia* since 1961; those pertinent to Wisconsin are listed in the bibliography. Much information regarding species ranges, descriptions of hybrids, and taxa of infrequent occurrence in Wisconsin has been taken from the publications of Dr. Moldenke, who, in addition to verifying the identification of most of our specimens, commented helpfully on this manuscript. Since Dr. Moldenke, above all others, has made an accurate treatment of the Wisconsin Verbenaceae possible, this report is dedicated to him.

This study is based primarily on specimens deposited in the herbaria of the University of Wisconsin-Madison (WIS), UW-Milwaukee (UWM), and the Milwaukee Public Museum (MIL), as well as UW-Oshkosh (OSH), UW-La Crosse (UWL), UW-Stevens Point (UWSP), UW-Superior (SUWS), UW-River Falls (RIVE), UW-Rock County Campus, Janesville (UWJ), the University of Iowa (IA), University of Minnesota (MIN), University of Michigan (MICH), Beloit College (BELC), the Morton Arboretum (MOR), Field Museum of Natural History (F), and the private herbarium of Mrs. K. Rill, Oshkosh. Grateful acknowledgment is extended to the administrators of these herbaria for loan specimens. Dr. Edward G. Voss, University of Michigan, Dr. Gerald Ownbey, University of Minnesota, and Vicki Funk, Ohio State University, provided distribution records of *Verbena urticifolia* to complete the range map for that species.

Each solid or hollow circle, square, or plus (+) symbol on the Wisconsin maps represents the exact location where specimens were collected; triangles indicate county records without specific locations. Dots on the United States map indicate specimen occurrence by county. Numbers in the state map insets record by month the number of specimens examined in flower or fruit, i.e. the phenology of the species.

Since the Verbanaceae, world-wide, are morphologically a most diverse group, the descriptions that follow refer only to the Wisconsin species.

VERBENACEAE Saint-Hilaire
Vervain Family

Herbs, shrubs, vines or trees in the tropics. Leaves (in ours) opposite, exstipulate, simple; blades entire to dentate, incised or cleft. Inflorescences axillary or terminal, ours in heads (*Phyla*) or spikes (*Verbena*). Flowers perfect, hypogynous, more or less irregular. Calyx lobes fused, campanulate to tubular or salverform, 2- or 5-lobed. Corolla with fused petals, funnelform or salverform, tube well developed, the limb 4- or 5-lobed, more or less weakly 2-lipped. Stamens 4, didynamous (2 long, 2 short), inserted on the corolla tube. Ovary superior, sessile, somewhat 4-lobed, 2-carpellate, 2- or 4-celled with one ovule in each cell. Fruit a dry schizocarp splitting into 2 (*Phyla*) or 4 (*Verbena*) nutlets at maturity.

A large, morphologically heterogeneous family, widely distributed throughout the world, most abundant in the tropics, with 76 genera and 3,400 species and subspecies (Moldenke 1971), the largest genera, *Vitex, Clerodendrum, Verbena* (including *Glandularia*) and *Lantana,* containing both widely used ornamentals and pernicious weeds. The hard, heavy, durable wood of teak (*Tectona grandis*) is economically important in many tropical areas.

The Verbenaceae, together with Lamiaceae (Labiatae), Boraginaceae, Callitrichaceae and Phrymaceae, comprise the order Lamiales, with 7800 species (Cronquist 1968). The Lamiales, Scrophulariales and Polemoniales comprise the super-order Tubuliflorae. The monotypic, temperate, herbaceous Phrymaceae (*Phryma leptostachya;* cf. Iltis 1957), sometimes included in Verbenaceae (Thorne 1976) or segregated as a separate family on the basis of its reduced and highly specialized ovary, is clearly derived from Verbenaceae (Cronquist 1976). Most closely related to Verbenaceae, but more advanced, are the Lamiaceae, distinguished by a gynobasic style, deeply 4-cleft ovary, sharply 2-lipped flowers, and aromatic foliage. In contrast, Verbenaceae have a terminal style, only slightly or unlobed ovaries, at most weakly 2-lipped flowers, and often nonaromatic foliage.

Key To Genera

A. Flowers in elongated spikes, these terminating stems and branches; calyx 5-lobed; and cylindrical; corolla 5-lobed fruits separating into 4 nutlets. . . . . 1. Verbena.

AA. Flowers in dense heads axillary on long, bare peduncles; calyx 2-lobed and compressed; corolla 4-lobed; fruits separating into 2 nutlets. . . . . 2. Phyla.

1. Verbena L. Vervain

Herbs, erect, ascending or procumbent, perennial. Leaves opposite, toothed, incised, lobed or pinnatifid. Inflorescences terminal or axillary, spicate, loose to dense, few to often many and paniculately arranged. Flowers small or rather large in Sect. Glandularia, solitary and sessile in the axil of a bractlet. Calyx tubular, 5-ribbed, unequally 5-toothed. Corolla salverform or funnelform, its tube curved, villous within, a ring of hairs closing its mouth, the limb spreading, weakly 2-lipped, 5-lobed, slightly zygomorphic. Stamens 4, inserted on the upper portion of the tube, included. Style one, 2-lobed, the anterior lob stigmatiferous. Ovary superior, with one ovule in each of four cells. Fruit enclosed by the mature calyx, splitting at maturity into four small, linear nutlets.

A highly complex genus of 206 species, 122 subspecific taxa and 49 hybrids, native primarily to the New World (Moldenke 1971), most frequent in the southcentral United States, Mexico, and South America, with three species native to the Mediterranean region, several American species are weeds in the Old World and many species widely cultivated ornamentals. The showy Section *Glandularia* is now often elevated to generic status (Umber, 1979).

Several Wisconsin species of *Verbena* (e.g. *hastata, stricta, urticifolia, bracteata*) contain in their leaves and stems the bitter glucoside Verbenalin. Verbenalin, with the disagreeable tasting seed oils, may provide a competitive advantage in Wisconsin pastures, the plants being selective ignored by livestock. Singly or in various combinations, these species (especially *V. stricta*) are abundant in grazed areas throughout southern and western Wisconsin.

Originally, the three most common Vervains were probably ecologically segregated, with *V. hastata* in marshes, *V. stricta* in prairies, and *V. urticifolia* in woodlands. Today however, disturbance in most areas has obliterated this separation, and our native Vervains not only flourish but hybridize in such disturbed habitats. Considering the ubiquitous joint occurrences of many of these species, the relative rarity of hybrids is remarkable.

Verbena officinalis has been attributed erroneously to Wisconsin on the basis of two specimens (WIS) collected at Baraboo, Sauk County in 1861 (Hartley 1966). Both are *V.* x *perriana* (*V. urticifolia* x *V. bracteata*), their pinnatifid leaves resembling those of *V. officinalis.*

KEY TO THE WISCONSIN SPECIES OF VERBENA

(Hybrids among the first five species are not separable in this key; cf. pp. 89-93, Figs. 1, 4, 5, and *The New Britton and Brown Illustrated Flora* 3: 126-127).

A. Sterile style-lobe not protruding beyond the stigmatic surface; flowers 3-9 mm long, 3-9 mm broad; calyx 1-6 mm long; flowers in elongate, slender spikes; native species (Section VERBENA).
- B. Spikes usually many, paniculate; fruiting calyx 1.8-3 mm long; corolla 2.5-4.5 mm broad.
  - C. Spikes slender, the fruiting calyces more or less remote; calyx 1.8-2.4 mm long; corolla dull white, its tube 1.8-2.5 mm long. .... 1. V. URTICIFOLIA.
  - CC. Spikes thick, densely flowered, the fruiting calyces imbricate; corolla deep blue, lavendar or purple (white in occasional albinos); calyx 2.5-3 mm long; corolla tube 3-4 mm long or more. .... 2. V. HASTATA.
- BB. Spikes solitary or in 3's; fruiting calyx 2.9-5-6 mm long; corolla 3-9 mm broad.
  - D. Stems prostrate-ascending, often forming extensive mats, 5-10 (20) cm tall; bracts divergent, foliaceous exceeding the calyx; leaves lobed or incised usually near the base. . . 3. V. BRACTEATA.
  - DD. Stems erect, 3-11 dm tall; bracts appressed, subulate-lanceolate, shorter than or equalling the calyx; leaves toothed, rarely lobed.
    - E. Plants sparsely strigose; leaves lanceolate to oblanceolate, 3-11 mm wide; rare in southeastern Wisconsin. 4. V. SIMPLEX.
    - EE. Plants densely pubescent; leaves elliptic to orbicular, 13-50 mm wide; common throughout southern Wisconsin. .... 5. V. STRICTA.

AA. Sterile style-lobe protruding beyond the stigmatic surface; flowers 10-30 mm long, 8-30 mm broad, very showy; calyx 8-15 mm long; flowers in flat-topped, foreshortened spikes; rare garden escapes (Section GLANDULARIA).

F. Corolla 20-30 mm long, 10-25 mm broad, the tube twice as long as the calyx.

G. Leaves appressed strigose or glabrate; flower rose to purple. .... 6. V. CANADENSIS.

GG. Leaves densely pubescent; flowers violet to red and white, often with a white central eye spot in the throat. .... 7. V. X HYBRIDA.

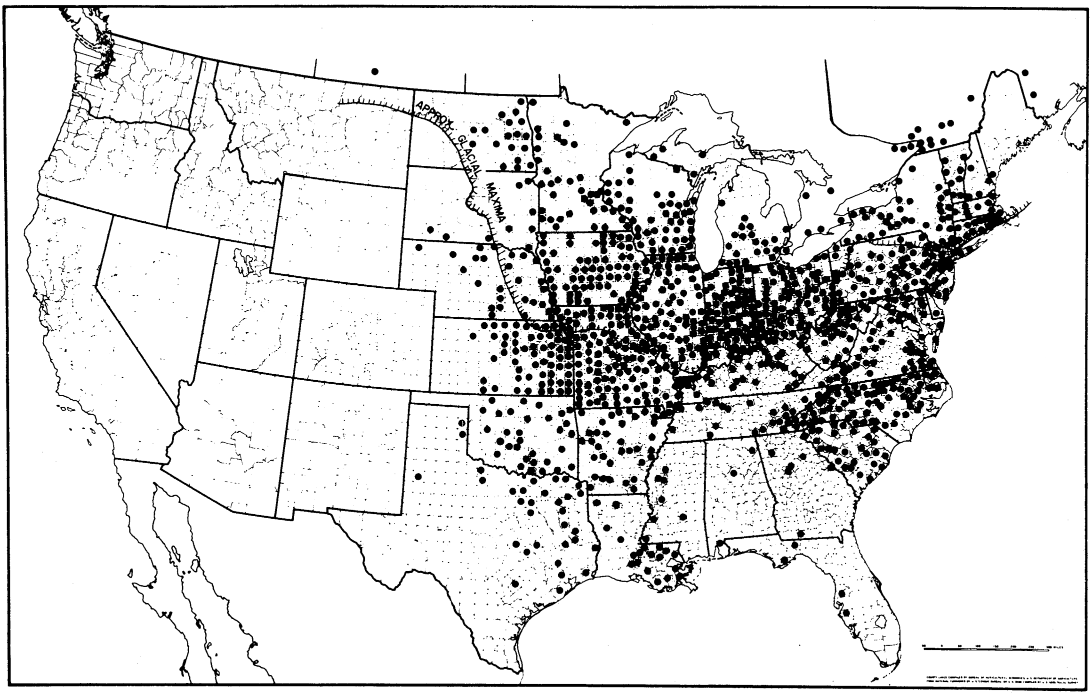
FF. Corolla 10-15 mm long, 8-10 mm broad, the tube 1.3-1.5 times as long as calyx; flowers rose to purple. .... 8. V. BIPINNATIFIDA.

SECTION VERBENA (NATIVE SPECIES)

1. VERBENA URTICIFOLIA L. Maps 1-3.

White Vervain, Nettle-leaved Vervain

Herb, perennial, 5-15 (−25) dm tall. Stems erect, simple or with ascending branches, quadrangular. *Leaves ovate* to elliptic, occasionally lanceolate, 4-14 cm long, 3-7 cm wide, with pustulate hairs above, subglabrous to densely velutinous beneath, acute, abruptly attenuated to the 1.5-3.5 cm long petiole, coarsely serrate or biserrate. Leaf hairs simple, sometimes gland-tipped on the main veins beneath. Spikes slender, becoming remotely fruited, 5-28 cm long, numerous in open panicles. Bractlets ovate-acuminate, 0.7-1.2 mm long. Calyx 1.8-2.4 mm long, minutely pubescent, the subequal teeth not connivent. Corolla *dull white,* slightly surpassing the calyx, 2.5-3.5 mm long, the tube 1.8-2.5 mm long. Nutlets oblong, 1.5-2.0 mm long, raised re-



MAP 1. North American distribution of *Verbena urticifolia* by country.

ticulate-striate. 2n = 14 (Lewis & Oliver 1961).

Widespread and common in eastern North America (Map 1), from Quebec to Saskatchewan south to Florida and Texas, in Wisconsin primarily south of the "Tension Zone" in a great variety of habitats, from dry oak to moist maple-basswood and floodplain forests, and sedge meadows (there modal, fide Curtis 1959), an aggressive weed tolerant of disturbance, common in grazed or cut-over woods, pastures, grazed or drained sedge meadows, roadsides, and railroad rights-of-way and other sunny or shaded, mesic and moist degraded sites.

Verbena urticifolia is one of the few native weeds frequently seen co-dominant with grasses in heavily grazed pastures. Here an obvious increaser (as is *V. stricta,* which may occur with it but in drier spots), it is avoided by cattle.

Flowering from the end of June through the end of September, fruiting from July through October.

Verbena urticifolia tends to be autogamous, its minute flowers setting seed whether excluded from or exposed to insect pollinators. Self-pollination occurs when the wilting of the persistent corolla allows the anthers to contact the stigma. Pollinating insects are chiefly flies (Perkins *et al.* 1975).

In Wisconsin, *Verbena urticifolia* hybridizes most frequently with *V. hastata* (*V.* x *engelmannii*) and rarely with *V. bracteata* (*V.* x *perriana*) and *V. stricta* (*V.* x *illicita*).

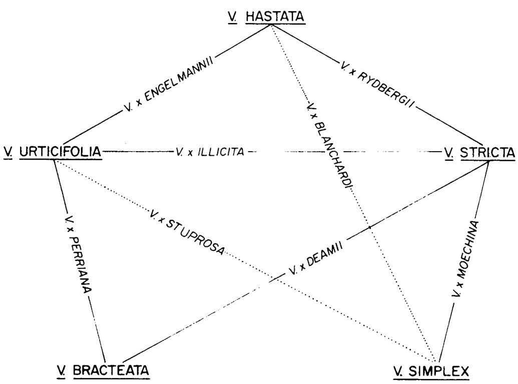


Fig. 1. Species of *Verbena* native to Wisconsin and their hybrids. Those connected by dashed lines have not been collected in the state.

	var. *urticifolia*		var. *leiocarpa*	
Character	Fernald (1936)	Wisconsin Material	Fernald (1936)	Wisconsin Material
● leaf pubescence	strigose-hirsute beneath with stiff hairs up to 1-1.3 mm long or glabrate	glabrate to strigose-hirsute beneath with hairs mostly 0.5-0.8 mm long, rarely to 1.1 mm long	velutinous or subvelutinous with minute hairs to 0.3 mm long	subvelutinous to densely velutinous with hairs up to 0.4 mm long
● glandular hairs	————	rare on sparsely hirsute specimens, more common on densely hirsute specimens, especially northward	————	stalked glandular hairs rare to frequent at the nodes, rachis, petioles and midveins on the ventral leaf surface
● inflorescence	stiffly ascending	ascending	lax	ascending
● calyx length	2-2.3 mm	1.5-2.5 mm	rarely to 2 mm	(1.75) 1.9-2.2 (2.4) mm
● bractlet length	1-1.5 mm	0.9-1.5 mm	0.5-1 mm	0.9-1.3 mm
● nutlet length	about 2 mm	1.55-2.05 mm	only 1.5 mm	1.6-1.9 mm
● nutlet ribbing	ribbed on the back	ribbed on the back	smooth on the back	ribbed on the back

Fig. 2. Characters utilized to distinguish *Verbena urticifolia* var. *urticifolia* and *V. urticifolia* var. *leocarpa*—after Fernald (1936) and from Wisconsin material identified by Moldenke.

A hybrid with *V. simplex* (*V* x *stuprosa*) has not been found here (Fig. 1).

VARIABILITY IN VERBENA URTICIFOLIA

Verbena urticifolia exhibits much variability, as expected of such a wide-ranging species occurring in diverse habitats. One of the variants has been segregated as var. *leiocarpa* Perry & Fernald (Fernald 1936). The characters originally used to separate the variety, as well as an additional one correlated with it, are listed in Fig. 2. In the original description, var. *leiocarpa* was said to occur from "Eastern Virginia to South Carolina" (and rarely northward to Connecticut), in contrast to the widespread distribution of the typical variety. While this variety was originally claimed to be a Coastal Plain endemic, Moldenke subsequently identified many of the Wisconsin specimens as var. *leiocarpa,* apparently on the basis of the velutinous pubescence on the underside of the leaves.

On the basis of Perry and Fernald's original taxonomic characters (length of calyx, corolla and bractlet, inflorescence angle, nutlet ribbing) the Wisconsin specimens of *Verbena urticifolia* can not be separated into two varieties. There is no correlation between calyx length, bractlet length and nutlet length for specimens separated into two varieties on the basis of pubescence (Fig. 3). Even Fernald's best distinguishing character, the soft pubescence on the underside of the leaves, is variable and intergrading. Nevertheless, it does seem to correlate slightly with geography, for var. *leiocarpa* is found primarily south of the Tension Zone in Wisconsin (Map 3), while the typical variety (Map 2) does range north of the Tension Zone, although infrequently. A similar, and hence significant, restriction of var. *leiocarpa* to more southerly areas has been reported for Western Pennsylvania (Jennings 1953). Correlated with distribution, again in a poorly defined way, are the additional characters of presence and relative abundance of gland-tipped hairs, these primarily on the rachis, petioles, upper nodes and midveins on the ventral leaf surface.

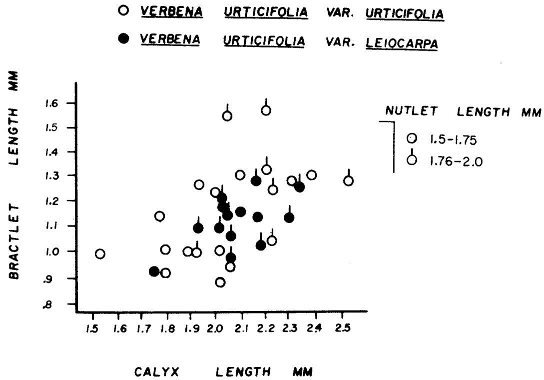
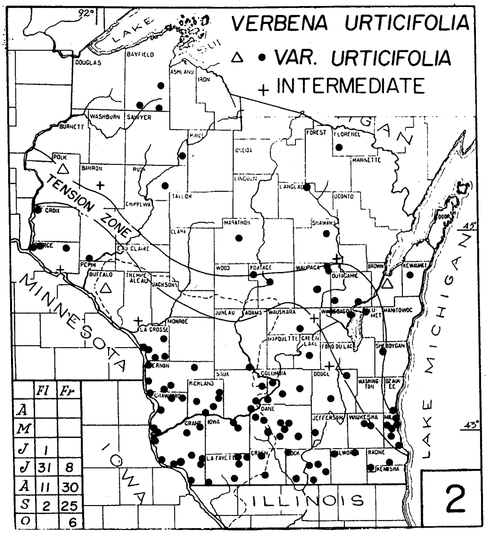
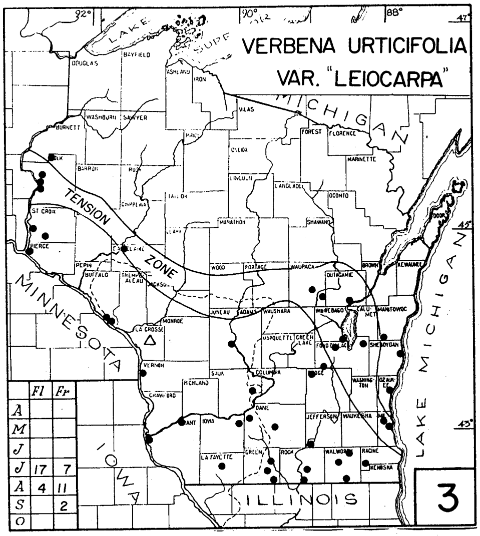


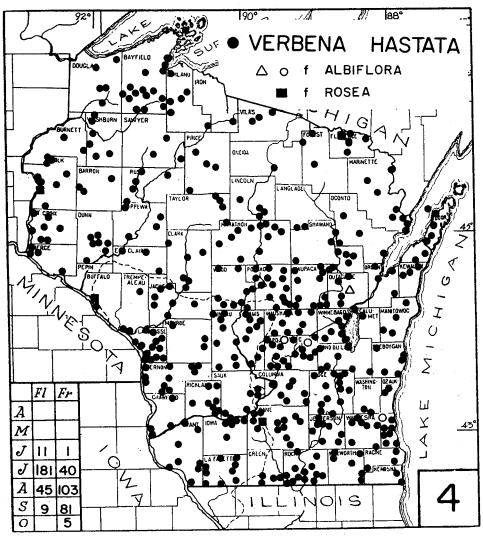
Fig. 3. Scatter diagram of Wisconsin specimens of *Verbena urticifolia* var. *urticifolia* and var. *leiocarpa* (determined by Moldenke) illustrating the lack of correlation between three of the taxonomic characters Fernald utilized to separate the variety.

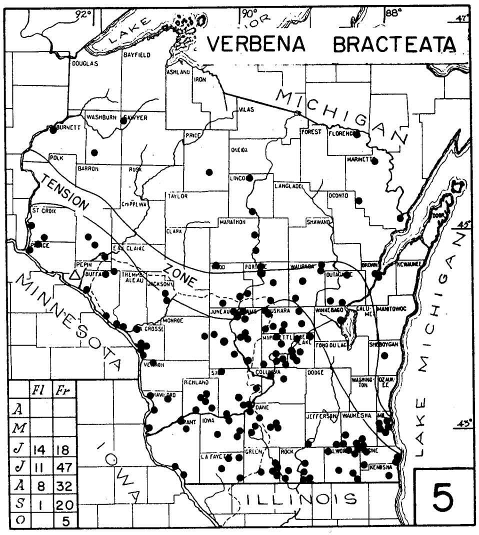
In summary, while these distinctions seem hardly worthwhile, the map and scatter diagram suggest that originally there may have been a Coastal Plain population differentiated from an inland one. With the waning of the Pleistocene ice, both varieties migrated into the formerly glaciated lands to become sympatric. With differential selection pressure relaxed, morphological distinctness was reduced by exchange of genetic material in many populations, and continued evolutionary divergence of the varieties was swamped through recombination. Perhaps the descendants of the Coastal Plain population are the velutinous ones which now seem to be restricted to the warmer parts of Wisconsin, a region harboring many Coastal Plain taxa.

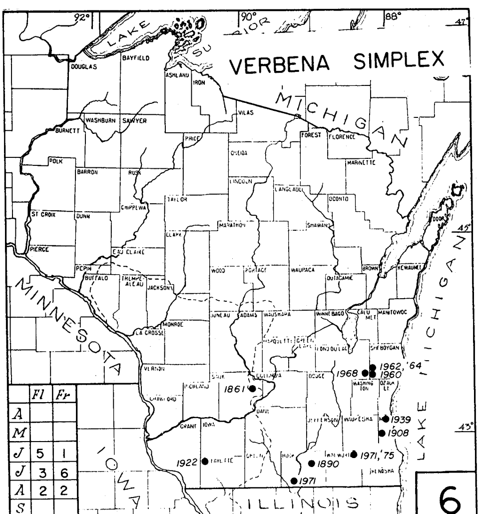
While most floras disregard Fernald's variety (e.g. Radford, et al. 1968), calling attention to such variability does serve a useful biogeographic purpose. Fernald, a genius at recognizing subtle plant variation in the

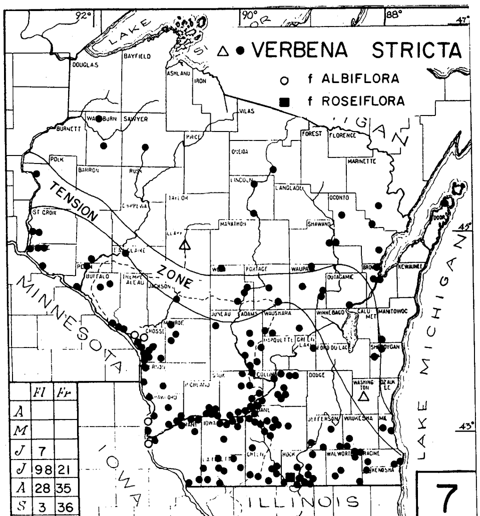

VERBENA URTICIFOLIA
△ • VAR. URTICIFOLIA
+ INTERMEDIATE
TENSION ZONE
MINNESOTA
IOWA
ILLINOIS
LAKE MICHIGAN
Fl Fr
A
M
J 1
J 31 8
A 11 30
S 2 25
O 6
2

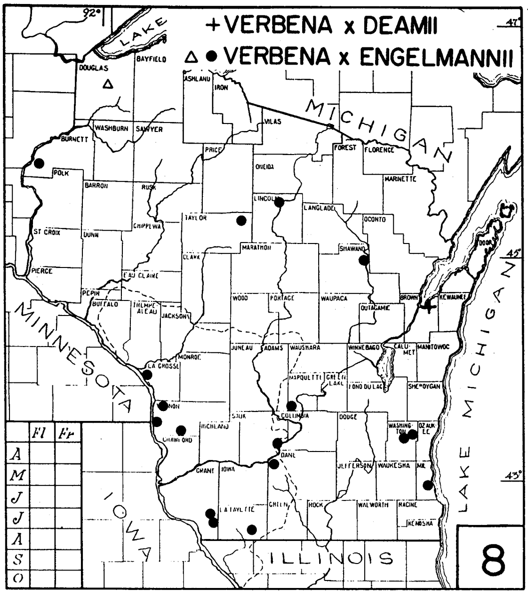

VERBENA URTICIFOLIA
VAR. "LEIOCARPA"
MICHIGAN
TENSION ZONE
MINNESOTA
IOWA
ILLINOIS
LAKE MICHIGAN
Fl Fr
A
M
J
J 17 7
A 4 11
S 2
O
3

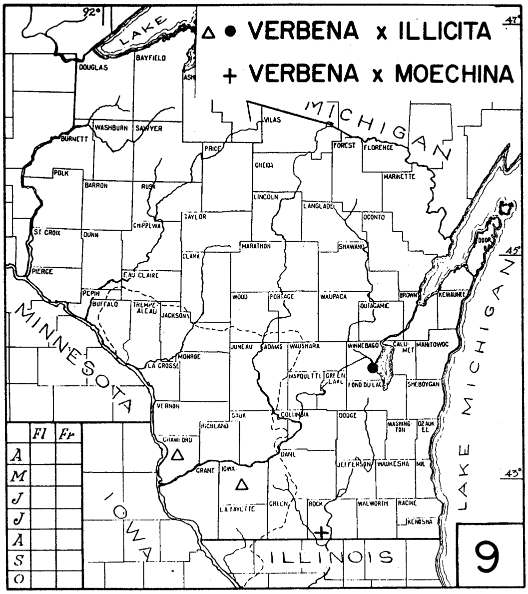

• VERBENA HASTATA
△ ○ f ALBIFLORA
■ f ROSEA
MICHIGAN
MINNESOTA
IOWA
ILLINOIS
LAKE MICHIGAN
Fl Fr
A
M
J 11 1
J 181 40
A 45 103
S 9 81
O 5
4

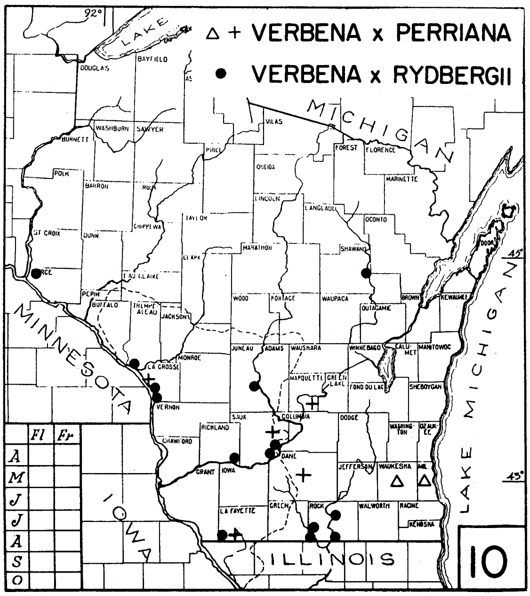

VERBENA BRACTEATA
MICHIGAN
TENSION ZONE
MINNESOTA
IOWA
ILLINOIS
LAKE MICHIGAN
Fl Fr
A
M
J 14 18
J 11 47
A 8 32
S 1 20
O 5
5

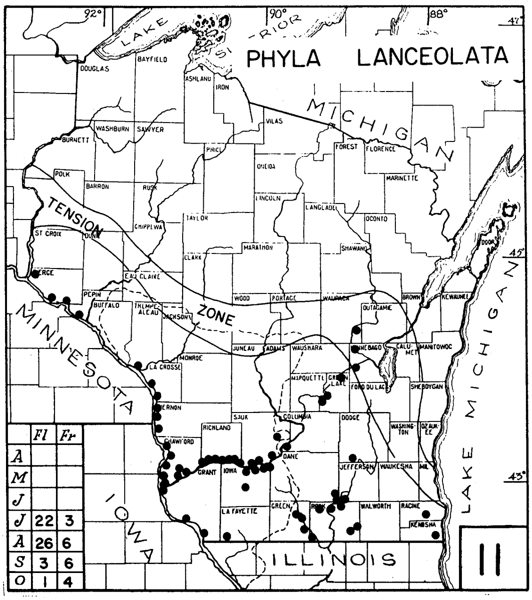

VERBENA SIMPLEX
MICHIGAN
MINNESOTA
IOWA
ILLINOIS
LAKE MICHIGAN
1962, '64
1960
1968
1861
1939
1908
1922
1890
1971, '75
1971
Fl Fr
A
M
J 5 1
J 3 6
A 2 2
S
6


△ • VERBENA STRICTA
○ f ALBIFLORA
■ f ROSEIFLORA
TENSION ZONE
MINNESOTA
IOWA
ILLINOIS
LAKE MICHIGAN
Fl Fr
A
M
J 7
J 98 21
A 28 35
S 3 36
7


+VERBENA x DEAMII
△ ● VERBENA x ENGELMANNII
LAKE
MICHIGAN
MINNESOTA
IOWA
ILLINOIS
LAKE MICHIGAN
Fl Fr
A
M
J
J
A
S
O
8


△ ● VERBENA x ILLICITA
+ VERBENA x MOECHINA
LAKE
MICHIGAN
MINNESOTA
IOWA
ILLINOIS
LAKE MICHIGAN
Fl Fr
A
M
J
J
A
S
O
9


△ + VERBENA x PERRIANA
● VERBENA x RYDBERGII
LAKE
MICHIGAN
MINNESOTA
IOWA
ILLINOIS
LAKE MICHIGAN
Fl Fr
A
M
J
J
A
S
O
10


PHYLA LANCEOLATA
LAKE
SUPERIOR
MICHIGAN
TENSION
ZONE
MINNESOTA
IOWA
ILLINOIS
LAKE MICHIGAN
Fl Fr
A
M
J
J 22 3
A 26 6
S 3 6
O 1 4
11

field, may not have been totally wrong! Only detailed population studies of this species throughout its range can resolve this question.

KEY TO VARIETIES

A. Leaves nearly glabrous to hirtellous beneath; hairs 0.5-1.1 mm long; gland-tipped hairs rarely present except in more densely pubescent specimens; nearly throughout Wisconsin. .... 1a. VERBENA URTICIFOLIA var. URTICIFOLIA.

AA. Leaves more or less densely velutinous below; hairs mostly less than 0.4 mm long; scattered gland-tipped hairs usually present on upper nodes, rachis, petolies and midrib of ventral leaf surface; mostly south of the Tension Zone. .... 1b. VERBENA URTICIFOLIA var. LEIOCARPA.

1a. VERBENA URTICIFOLIA L. var. URTICIFOLIA Map 2.

1b. VERBENA URTICIFOLIA L. var. LEIOCARPA Perry & Fernald Map 3.

Morphological intermediates between these ill-defined variants possess either a dense pubescence of mixed long and short hairs with gland-tipped hairs, or a sparse but very short pubescence without or with few gland-tipped hairs, in each example illustrating continuous variation. These are indicated on Map 2 with plus symbols.

2. VERBENA HASTATA L. Blue Vervain, Simpler's Joy Map 4.

Verbena hastata L. var. *scabra* Moldenke

Herb, perennial, 2-13 dm tall. Stems erect, 1-several, simple or ascending branched, scabrous with short antrorse hairs on the angles. Leaves to 15 cm long, 5.5 cm wide, narrowly ovate to elliptic, on narrow winged petioles, reduced upwards, gradually accuminate and rounded at base, coarsely serrate or biserrate, *the larger sometimes* hastately lobed, scabrous to rough hirsute on both surfaces but softer beneath. Spikes 5-12 cm long, rarely solitary, usually numerous in a dense terminal panicle, erect and densely many-flowered. Bractlets 1.8-2.8 mm long, lanceolate-subulate, shorter than the calyx. Calyx 2.5-3.0 mm long, its acute lobes with subulate, connivent tips. Corolla deep lavender or purple (white in forma ALBIFLORA Moldenke, rose in forma ROSEA Cheney), 3-4.5 mm broad, the tube 3-4 mm long surpassing the calyx. Nutlets linear, 1.8-2.1 mm long, faintly striate. 2n = 14 (Mulligan 1961).

Widespread from Nova Scotia to British Columbia, south to Florida, Texas, and Arizona, but only sporadic in the Western States, rare in the Southern and Southeastern States (cf. Moldenke 1963b for map), in Wisconsin the most common Vervain, occurring in a variety of usually moist, sunny habitats, as in marshes, stream edges, lake shores, shrub-carrs, low prairies, sedge meadows (where modal: Curtis 1959), and rarely in moist forests, tolerating much habitat disturbance, hence common in heavily grazed pastures, roadsides and railroad rights-of-way, and occasionally abandoned sandy fields.

Flowering from late June through September, fruiting from early July to mid-October.

In describing var. *scabra,* Moldenke (1963b) states that "This variety differs from the typical form of the species in having its leaf blades more rigid, conspicuously scabrous above, and often more or less conspicuously pubescent beneath," and later (1971), "Probably most, if not all, of the material now passing as *Verbena hastata* from west of the Mississippi, or at least, west of the Great Plains, is actually var. *scabra.*" While Moldenke has identified specimens from several counties in the state as var. *scabra,* all Wisconsin specimens of *V. hastata* are rough hispid to scabrous above and pubescent beneath, and seem to be part of the western, more scabrous end of a subcontinental, taxonomically indivisible cline.

In Wisconsin, *Verbena hastata* hybridizes with *V. stricta* (*V.* x *rydbergii*) and *V. urticifolia* (*V.* x *engelmannii*). A hybrid with *V. simplex* (*V.* x *blanchardi*) has not been collected here (Fig. 1).

3. VERBENA BRACTEATA Lag. & Rodr. Creeping Vervain, Large-bracted Vervain Map 5.

Verbena bracteosa Michx.

Herb, perennial. Stem *prostrate-ascending,* diffusely branched from a thickened tap root, to 6 or more dm long, 5-20 cm tall, often forming large, round mats, coarsely hispid-hirsute. Leaves 1-4.5 cm long, 0.8-3.2 cm wide, lanceolate to ovate, *pinnately incised or 3-lobed,* gradually narrowed into a short petiole. Spikes few to many, elongating in fruit, densely flowered and conspicuously bracteate. Bractlets *7-13 mm long and much longer than the calyx,* foliaceous, spreading to recurved in age, hirsute. Calyx 2.9-4.3 mm long, white-hispid, the acuminate lobes connivent. Corolla lavender-purple to pink, 2.5-4.0 mm broad, the tube about 4 mm long and slightly exsert from the calyx. Nutlets linear, 2-2.5 mm long. $2n = 14$ (Jackson 1960).

Wide ranging from Maine to British Columbia, south to Florida, Texas, and Mexico (cf. map in Moldenke 1962b), and introduced in Western Europe, in Wisconsin primarily south of the Tension Zone, a weed (Curtis 1959) of droughty and sunny disturbed habitats as sandy or gravelly roadsides, railroad rights-of-way, quarries, open woods, sandy river terraces, trails, and waste places in towns.

Flowering from the first week in June, fruiting from mid-June through October.

Once established, the ability of Creeping Vervian to persist is exemplified by a Richland County collection (*Nee 13,460, WIS*) where it is reported to be "common, in decumbent mats in heavily grazed hog lot . . . now the only living plant."

Although common and apparently indigenous, it appears not to be part of any native plant community (Swink 1974), excepting perhaps sandy river terraces and dry rocky exposed cliffs where it is rarely collected. These, supposedly undisturbed sites include Brady's Bluff Prairie (Trempealeau County), Ferry Bluff (Sauk County), and Observatory Hill (Marquette County), all rocky, xeric "open" habitats with minimal competition characterized by bedrock exposures and shallow soils.

But even the earliest Wisconsin collections stress disturbance: "A roadside weed very plentiful in some places" (*Lapham s.n.,* Waukesha Co., 11 Aug. 1847, *WIS*): ". . . in waste places" (*Cheney s.n.,* Lafayette Co., 27 Aug. 1888, WIS); "On ballast of C.M.St.P.&P. RR near University Farm." (*Heddle 706,* Dane Co., 1 Aug. 1907, MIL). C. C. Parry (1852), who cataloged the plants during a geological survey of Wisconsin, Minnesota and Iowa in 1848, characterized the habitat of *V. bracteata* as "roadsides." Although the plant probably existed in Wisconsin prior to settlement certainly its frequency has increased greatly from the time of the first settlers.

Capable of autogamy, *Verbena bracteata* shows a tendency for cross-fertilization, with butterflies the primary visitors (Perkins *et al.* 1975).

In Wisconsin, *Verbena bracteata* hybridizes with *V. stricta* (*V.* x *deamii*) and *V. urticifolia* (*V* x *perriana*) (Fig. 1).

4. VERBENA SIMPLEX Lehm. Narrow-leaved Vervain Map 6.

Verbena angustifolia Michx.

Herb, perennial, 2.8-5 dm tall. Stems erect, and simple, or ascending and sometimes spreading branched, sparsely strigose. Leaves 4.5-7.5 cm long, *3-11 mm wide,* *linear to narrowly oblong or spatulate,* tapering to a subsessile base, serrulate often only toward the acute apex, sparsely strigillose to scabrous on both surfaces. Spikes 3-24 cm long, slender, stiffly erect. Bractlets 2.5-4.3 mm long, lanceolate-subulate, shorter to as long as the calyx. Calyx 3-4.5 mm long, the five accuminate lobes erect to spreading in fruit. Corolla light blue to purple or rose, 5-7.1 mm broad, the tube 3.8-4.8 mm long, slightly surpassing calyx. Nutlets linear, 2.3-3 mm long, raised reticulate above, striate below. 2n = 14 (Noack 1937).

Widespread from New Hampshire and Massachusetts to Ontario, southern Minnesota, and Nebraska, south to Florida and Oklahoma (cf. map in Moldenke 1964c), in Wisconsin only in the southern third, where rare in open, dry, calcareous sites such as gravelly moraines, roadsides, or railroad rights-of-way.

Flowering from mid-June through mid-August, fruiting late June to September.

In Wisconsin, *V. simplex* hybridizes with *V. stricta* (*V.* x *moechina*). Hybrids with *V. hastata* (*V.* x *blanchardi*), and *V. urticifolia* (*V.* x *stuprosa*) are not known from Wisconsin (Fig. 1).

5. VERBENA STRICTA Vent.
Hoary Vervain Map 7.

Verbena stricta Vent. forma *albiflora* Wadmond, in *Rhodora* 34:19. 1932. (Type: "southeastern Wisconsin," in Gray Herbarium Harvard U. (?), not seen).

Herb, perennial, 2.9-11 dm tall. Stems erect, robust, simple to branched, *densely pubescent.* Leaves 3.2-9.4 cm long, 1.3-5 cm wide, *narrowly elliptic, orbiculate, or widely ovate,* sessile or nearly so, sharply serrate, biserrate or irregularly incised-serrate, thick-textured, *hirsute and rugose above, densely canescent below. Spikes usually 1,* or 3 to 5, or more, *thick and stiffly erect,* hirsute throughout, to 3.1 dm long. Bractlets 3.8-5.6 mm long, lanceolate-subulate, hirsute, shorter or equalling the calyx. Calyx 3.8-5.6 mm long, densely hirsute, its five lobes acuminate. Corolla purple, lavender or blue (pink or rose in forma ROSEIFLORA Benke, white in forma ALBIFLORA Wadmond) 7.5-9 mm wide, the tube 3.8-6.4 mm long, surpassing the calyx. Nutlets ellipsoid, 2.3-3 mm long, raised reticulate above, striate below. 2n = 14 (Noack 1937).

A native of the Great Plains, from Ontario and Ohio to Montana, south to Texas, Arizona, and Mexico (cf. map in Moldenke 1964c), in Wisconsin south of the Tension Zone in many dry, sunny habitats such as xeric and sandy prairies, limey or "goat prairies" (here modal, Curtis 1959), abundant in heavily grazed, sandy or gravelly pastures or abandoned fields, less frequently in open oak or oak-jack pine woods, roadsides, and railroad rights-of-way.

Flowering from late June to early October, fruiting from early July through October.

In studying effects of grazing on thin soil Wisconsin prairies, Dix (1959) gave *V. stricta* a high negative grazing susceptibility rating because of its greatly increased frequency on grazed hill prairies.

Capable of autogamy as are many weeds, *V. stricta* shows a tendency for cross fertilization due to partial self-incompatibility. Selfing is thwarted by the position of the corolla tube which, horizontal and partially closed by hairs, prevents pollen falling onto a stigma unreceptive until anthesis. Insect visitors are equally divided between Diptera, Hymenoptera, and Lepidoptera (Perkins *et al.* 1975).

In Wisconsin, *V. stricta* hybridizes with each of the other four native species (Fig. 1), but most commonly with *V. hastata* (*V.* x *rydbergii*).

SECTION GLANDULARIA Schauer
(Adventive Species) (See Umber 1979)

6. VERBENA CANADENSIS (L.) Britton
Rose Vervain

Herb, annual or perennial. Stems erect or decumbent, often rooting at the nodes, glabrous to spreading-hirsute. Leaves coarsely *incised, pinnatifid or 3-cleft,* glabrous to hirsute on both sides. Spikes with many large flowers in flat-topped, showy clusters. Bractlets mostly shorter than calyx. Calyx 10-13 mm long, glandular-hirsute, with subulate lobes. *Corolla usually purplish-rose, 11-15 mm broad,* the tube about twice as long as the calyx. Nutlets 3-3.5 mm long. 2n = 30 (Dermen 1936).

Common from Pennsylvania, Tennessee and Colorado south to Florida and Texas, most abundant in the Ozarks, cultivated and sometimes naturalized in Minnesota and southern Michigan (cf. map in Moldenke 1962c), its seeds available commercially and in Wisconsin occasionally planted in cemeteries or flower gardens. Two specimens were observed: "in landscaped roadside gravel," (Walworth County, T4N R18E NE¼SW¼ Sect. 7, Sept. 4, 1975 *Tans 1976*); "dry roadside, south shore Lake Wingra, UW-Arboretum," (Dane County, Sept. 5, 1971 (*Reardon 045,* OSH).

7. VERBENA X HYBRIDA Voss ex Rumpler
Garden Verbena

Herb, annual or perennial. Stems freely branched, procumbent, forming mats to 1 m wide, densely hirsute or villous. Leaves 1.5-8 cm long, 1.5-8 cm wide, *dentate,* truncate to cuneately narrowed to petiole, both sides densely soft pubescent. Spikes a flat-topped corymb, the flowers large and showy. Bractlets 5-6 mm long, lanceolate, shorter than calyx, densely soft pubsecent. Calyx 8-15 mm long, densely white-hirsute. Corolla showy, variously colored (blue, deep violet, red, etc.), usually with a prominent *central white "eye,"* 10-25 mm broad, the tube 15-30 mm long.

A polymorphic hybrid of uncertain ancestry, supposedly involving the South American *V. platensis, V. phlogiflora, V. incisa, V. peruviana,* and *V. tenera* (Moldenke 1963b), commonly cultivated as an ornamental throughout the world, known in Wisconsin only from gardens since at least the 1860's (*T. J. Hale s.n.* WIS). 2n = 10, 20 (Furusato 1940).

8. VERBENA BIPINNATIFIDA Nutt.
Cutleaf Verbena

Herb, annual or perennial. Stems erect or procumbent, diffusely branched, hispid-hirsute. Leaves 2-6 cm long, ovate in general outline, delicately bipinnatifid or tripinnatifid with the divisions deeply cleft. Spikes, canescent, with showy flowers in dense flat-topped clusters. Bractlets 8-9 mm long, narrowly lanceolate, surpassing the calyx. Calyx 6-7.5 mm long with 2-3 mm long setaceous teeth. Corolla pink to rose, purple or blue, *8-10 mm wide,* the tube about 10 mm long and 1.3-1.5 times as long as the calyx. Nutlets cylindric, 2-3 mm long. 2n = 30 (Solbrig 1959).

Primarily a Great Plains and southwestern United States species, ranging from South Dakota to Missouri and Georgia, west to Texas and Arizona (cf. map in Moldenke 1962a), the only Wisconsin collection from a Green County roadside (T3N R9E Sect. 21, May 24, 1969, *Maurer 311* OSH).

HYBRIDIZATION AMONG NATIVE SPECIES OF VERBENA

The Vervains native to Wisconsin (Sect. VERBENA) are all wide ranging sympatric species interfertile with one another. All are diploid, with x = 7 (2n = 14). Ecological factors, no doubt, were responsible for isolating species and preventing hybridization in pre-settlement times. Now, however, Vervains are common in many disturbed sites, especially where human activities have eradicated some or all of the native flora, as for example in pastures. Of the three *Verbena* hybrids in Kansas studied by Poindexter (1962), all were found in overgrazed pastures, roadsides or waste places.

Hybridization is enhanced not only by their tolerance of disturbance, with the resultant breakdown of ecological isolation, but also by their extended flowering periods (2½ to 3½ months), allowing any two spe-

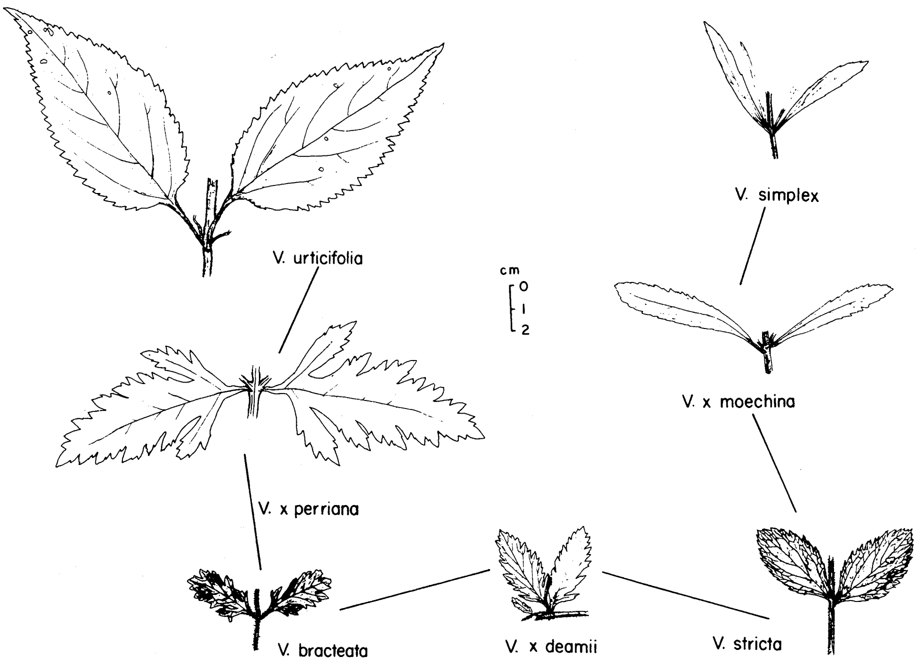


Fig. 4. Middle stem leaves of *Verbena urticifolia, V. bracteata, V. stricta* and *V. simplex* and their hybrids native to Wisconsin.

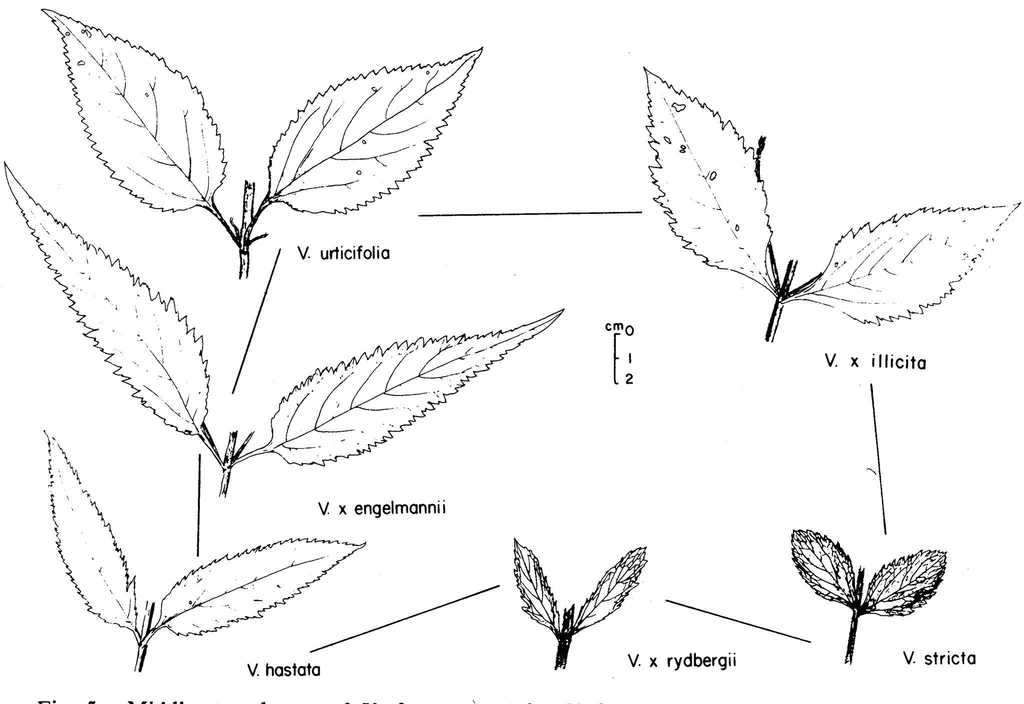


Fig. 5. Middle stem leaves of *Verbena urticifolia, V. hastata* and *V. stricta* and their hybrids native to Wisconsin.

cies to flower contemporaneously, and by the wide variety of pollinators from many insect orders.

Even though first generation hybrids are relatively common in *Verbena,* the vast majority of Vervains encountered in the field are not hybrids. Introgression, apparently, is limited, for the distinctness of the parental species has not been reduced as, for example, in *Tradescantia, Iris,* or *Helianthus.* As the parental species themselves are well adapted to disturbed sites, such introgressants may have no competitive advantage, and, due to partial sterility, may have relatively short survival.

The following six hybrids occurring in Wisconsin often can be recognized by intermediate leaf shape (Figs. 4, 5), pubescence, flower size, and inflorescence, as well as reduced fertility, and the nearby presence of their parental species.

VERBENA X DEAMII Moldenke
Deam's Vervian Map 8.

Intermediate between *V. bracteata* and *V. stricta.* Ascending to procumbent, resembling *V. bracteata* in habit, but with larger, less laciniate, and reticulate leaves, larger flowers, and bractlets usually not foliaceous, the spikes more slender than in *V. stricta,* often poorly fruited, the leaves, stems, branches and inflorescences softly villous.

Known from the central United States where the parental species are sympatric, in Wisconsin, from Brown County ("Bay Settlement" July 19, 1883, *Schuette s.n.,* DS), this erroneously attributed by Moldenke (1963a) to Pierce County, perhaps because the town of "Bay City" is located there.

VERBENA X ENGELMANNII Moldenke
Engelmann's Vervain Map 8.

Intermediate between *V. hastata* and *V. urticifolia.* Resembling *V. urticifolia* but with denser, often poorly-fruited spikes usualy with overlapping calyces, and blue to purple flowers, the leaves coarsely serrate to biserrate, larger than those of *V. hastata,* the leaves, stem, branches and inflorescences from nearly glabrous to evenly pubescent. Corolla tube and calyx intermediate in length, and pollen fertility reduced (Poindexter 1962).

Occurring in northeastern United States where the parental species are sympatric, in Wisconsin known from some 17 collections from moist open woods, roadsides, stream edges and wet meadows.

VERBENA X ILLICITA Moldenke
Bastard Vervain Map 9.

Intermediate between *V. stricta* and *V. urticifolia.* Resembling *V. urticifolia* in habit, the spikes denser with some of the mature calyces overlapping, often poorly fruited, but similar to *V. stricta* in its densely pubescent leaves, stems, branches and inflorescences. Nutlet length and ribbing and calyx and corolla lengths intermediate, the pollen fertility greatly reduced (Poindexter 1962).

Known primarily from the central United States where the parental species are sympatric, in Wisconsin only from Crawford (*A. R. Moldenke 995,* KANU, U), Iowa (*A. R. Moldenke 1003* KANU) (Moldenke 1965) and Winnebago Counties (Oshkosh, July 30, 1909, *M. K. Clemens s.n.,* POM) (Moldenke 1964a).

VERBENA X MOECHINA Moldenke Map 9.

Intermediate between *V. simplex* and *V. stricta.* Resembling *V. simplex* in habit, with oblanceolate leaves, but with a dense, short pubescence on leaves and stem, as well as smaller flowers and shorter bractlets, often poorly fruited.

In Wisconsin known only from Rock County "on north side of St. Lawrence Ave., 1.4 miles west of Paddock Road, T1N R11E Section 36," (*Souter & Rice 1692,* July 31, 1972 *BELC UWJ*), (*Tans 1431,* August 23, 1975 *WIS*), a small population in roadside gravel and in an abandoned limestone quarry, growing with *V. stricta* and such prairie plants as *Asclepias verticil-*

lata, Andropogon gerardi, Eragrostis spectabilis. Kuhnia eupatorioides, Ratibida pinnata, and *Solidago nemoralis.* While the other parent, *V. simplex,* could not be found nearby, a notation on the sheet of V. simplex collected from Rock County (*Furnish s.n.,* July 24, 1971, UWJ) by W. Rice suggests that it may be mislabeled, its probable collection site being a small gravel pit in Sect. 36, Newark Township, this, in fact, the site of *V.* x *moechina.*

VERBENA X PERRIANA Moldenke
Perry's Vervian Map 10.

Intermediate between *V. bracteata* and *V. urticifolia.* Sometimes a large, diffuse plant, stouter than *V. bracteata* and erect when young, often decumbent at maturity, the leaves much larger than in *V. bracteata,* laciniate, the larger often with two basal lobes characteristic of *V. bracteata,* the *bracteata,* the bractlets equalling to surpassing the calyx.

Known from eastern and central United States where the parental species are sympatric, in Wisconsin from Sauk Co. (Baraboo in 1861, *Hale s.n.,* WIS); Dane Co. (1858, *Shears s.n.,* WIS; Madison in 1860's?, *Hale s.n.,* WIS); Waukesha Co. (Aug. 22, 1891, *Dunlap 9163,* MIL); and Marquette Co. (roadside, T14N R10E NW¼ Sect. 31, Oct. 3, 1958, *Iltis 12,361,* WIS). According to Moldenke (1964b), known from La Crosse Co. (La Crosse, July 20, 1887, *L. H. Pammel s.n.,* ISC); Lafayette Co. (Shulsburg, July 19, 1883, *Manning s.n.,* NY); and Milwaukee Co. (*J. S. Douglas s.n.,* WJC).

VERBENA X RYDBERGII Moldenke
Rydberg's Vervian Map 10.

Intermediate between *V. stricta* and *V. hastata* and resembling either parent. Leaves wider and more deeply serrate than *V. hastata,* but reticulate and velutinous beneath, fruits irregularly produced. Intermediate in leaf length/width ratio, nutlet length, corolla and calyx lengths with pollen fertility greatly reduced (Poindexter 1962).

Occurring in central and eastern United States where the parental species are sympatric, in Wisconsin known from some 15 collections from river bottom forests, dry prairies and, most frequently, roadsides and pastures.

2. PHYLA Lour. Fog-fruit

A small, mostly tropical New World genus of 10 species with only the following in Wisconsin:

1. PHYLA LANCEOLATA (Michx.) Greene
Fog-fruit Map 11.

Lippia lanceolata Michx.
Lippia lanceolata Michx. var. *recognita* Fern. & Grisc.

Herb, perennial. Stems *creeping,* to 8 dm long, simple or branched at the base and *rooting at the nodes,* occasionally with ascending flowering branches, evenly pubescent with *short malpighiaceous* (attached at their center) *hairs.* Leaves 2-8 cm long, 6-30 mm wide, lanceolate to narrowly ovate, sharply serrate above the middle, evenly pubescent on both surfaces. Heads dense, *borne singly or in pairs from middle and upper leaf axils on 4-12 cm long peduncles,* at first globose, later to 15 cm long and cylindrical. Flowers sessile, solitary, in the axils of short bractlets 2-3 mm long. Calyx membranous, 2 mm long, compressed and keeled, 2-fid. Corolla white or flushed with purple, 2.5-3 mm long, salverform the slender tube cylindrical, surpassing the calyx, the limb oblique, somewhat 2-lipped, 4-lobed. Stamens included to barely exserted. Fruit globose, 1-1.2 mm long, dividing into 2 nutlets. $2n = 32$ (Smith 1966); $2n = 36$ (Lewis 1961).

Widespread across the United States and northern Mexico, in Wisconsin south of the Tension Zone, a "tropical element" of open habitats such as sunny, dry to wet sands or silt along major streams, most frequent along the lower Wisconsin and Mississippi Rivers on gravel bars and sandy mudflats, upstream as far as Columbia and Pierce Counties, also along the lower Kickapoo River, Galena River in Lafayette County, Sugar and Rock Rivers and Fox and Wolf Rivers in Winnebago and Waupaca Counties, occasionally on bare lake shores.

Flowering from the second week of July through the first week in October, fruiting from late July through October.

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A MASS BALANCE OF NITROGEN IN WISCONSIN

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Abstract

A mass balance of nitrogen (N) in Wisconsin, with emphasis on the flows and reservoir sizes in agriculture, was constructed. The model assumes steady state and is on an annual basis. The data used were available statistics and literature values. The calculations show that fixation of N by legumes is an important component of the agricultural nitrogen balance, estimated at about 2.5 times the inputs of N from fertilizer. The N fixed by legumes, when cycled through animals and returned as wastes or when plowed under as residues, is a major input to the soil organic N, and eventually available N pools. Further evaluation of this phase of the cycle, particularly the net mineralization estimate, is needed. Such evaluation is required to improve the efficiency of use of N fertilizer and minimize agricultural impacts on the environment.

INTRODUCTION

Nitrogen is a key element in crop production; of the essential elements supplied from the soil or fertilizers, it is required in the highest amounts and is the element most often inadequate (Viets, 1965). Recent increases in fertilizer nitrogen prices resulting from rising energy costs have focused attention on the need for a better understanding of N in agriculture. Of equal importance are the potential environmental impacts of the increased flow of fixed N from man's activities. These include: high nitrate in potable waters, associated with toxicities from methemoglobinemia (NRC, 1978); excessive productivity (eutrophication) of surface waters (Keeney, 1972); formation of carcinogenic nitrosamines (NRC, 1978); and ozone depletion in the stratosphere linked to production of nitrous oxide during denitrification (Crutzen and Ehalt, 1977).

Evaluation of human influence on the flows and storage of N in the environment is difficult because of the numerous diffuse sources of N, and its many biological and chemical conversions. A first and important step in this evaluation is the construction of a materials (mass) balance. A mass balance permits study of the behavior of an element or compound in a defined system. This is contrasted to the more common pollution monitoring methods, which are expensive and do not detect serious impacts until after they have occurred. The mass balance method emphasizes interactions between components in the system and thus facilitates prediction of future impacts. Further, it serves as an organizational tool and permits evaluation of information gaps and data needs.

The mass balance approach also has formidable problems. Usually the data base is insufficient, and verification by independent method is difficult. The degree of aggregation of various pools and transformations is also important; usually aggregation increases as the complexity of the system increases. For example, a global mass balance for N would have much higher degree of aggregation than a confined laboratory system. Assigning ecosystem boundaries is also a problem. Since N transfers are linked to atmospheric and water transport vectors, political boundaries are seldom realistic. However, they have the dual advantage that the data base is more readily defined from available

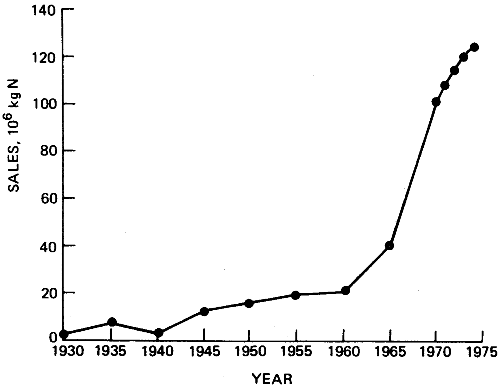

Fig. 1. Nitrogen fertilizer sales in Wisconsin, 1930-1975. Data from Wisconsin Department of Agriculture, October 1975.

statistics, and practical decisions on material flows are often made at the political level.

My colleagues and I often deal with difficult questions about the sources, fate and impact of N in Wisconsin agriculture. The exercise reported here is an attempt to construct a meaningful statewide N mass balance at low cost. Data are from published statistics and the scientific literature. A steady-state system is assumed, and the flows are on an annual basis.

The State

Wisconsin is largely a rural state, with a mixed cash grain, dairy, vegetable crop, and general farm-based agriculture. The total area is 14.64 $\times$ 10^6 ha, with 54 percent in farmland. In 1974, there were 105,000 farms, averaging 75.6 ha. The population was 4.6 million, with a heavy concentration around Milwaukee and its surrounding counties. About 179,000 workers are employed on farms. In 1973, gross farm cash receipts were $2,540 million, with dairy products accounting for $1,198 million and livestock products for $690 million of the gross income (Wisconsin Agricultural Statistics, 1975).

TABLE 1. Area in corn grown for grain, rate of application of nitrogen fertilizer, crop yield, and nitrogen removal in grain for Wisconsin, 1964-1974.

Year	*Hectares*	*Fertilizer N applied*	*Average yield*	*Crop N removed*
		kg/ha		
1964	577,000	32	4710	65
1968	710,000	70	5960	82
1970	752,000	76	5150	71
1972	867,000	89	5960	82
1974	919,000	70	4270	59

Nitrogen Inputs

Fertilizer

The use of nitrogen fertilizer has increased rapidly in Wisconsin in the past decade (Fig. 1). In 1974, Wisconsin used 127 $\times$ 10^6 kg, about 1.5 percent of the U.S. consumption of 8.5 million metric tons.

The area in corn grown for silage, about 400,000 ha, has remained roughly constant in recent years. However, the area devoted to corn that is grown for grain increased more than 59 percent in the past decade, and the average fertilizer N rates have more than doubled (Table 1). The statewide average yields of corn (about 80 percent of the corn grain is raised in the southern and eastern portions of the state) reflect the effects of weather, however, more than they do N fertilizer rates. For example, the summer of 1970 was hot and dry, and corn yields suffered from lack of moisture. In 1974, a late spring coupled with an early killing frost resulted in a short growing season and low yields. Hence, in 1974 (the year I chose for this balance) N removal by corn was below average.

Nitrogen Fixation

Symbiotic N fixation, mainly by alfalfa, is a major part of Wisconsin's agricultural N budget (Table 2), but the amount of N added to the soil when an alfalfa stand is plowed under is difficult to estimate. There are no data on accumulation of N by plant roots for stands of alfalfa more than 6 to 9 months old. Several long-term experiments with crop rotations under conditions found in Wisconsin indicate that an alfalfa

TABLE 2. Nitrogen removal by legumes in Wisconsin.

Crop	10^3 ha	N removed[a] kg/ha	N removed[a] 10^6 kg	Residual N kg/ha	Residual N 10^6 kg
Alfalfa	1,215	162	197	56	68
Mixed hay[b]	385	88	34	28	11
Soybeans	88	72	6.3	−24	−2
Snap beans	25	13	0.4	0	0
Field peas	53	26	1.4	0	0
Total	1,766		239		77

[a] From estimates in Boone and Welch (1972), Johnson et al. (1975), Welch (1972), and Wisconsin Agricultural Statistics (1975).
[b] Largely red clover and timothy mixture.

meadow will supply the equivalent of about 120 to 135 kg/ha of fertilizer N (Rohweder and Powell, 1973; Shrader and Pierre, 1966). The availability of N in legume residues ranges from 28 to 50 percent of the equivalent amount of fertilizer N (Shrader and Pierre, 1966). Assuming that the uptake of fertilizer N is about 70 percent, the residues of N in alfalfa amount to about 170 kg/ha. Since these residues accumulate over the lifetime of the average crop rotation (about 3 years in Wisconsin), I estimated the input of alfalfa-N to the soil reserve at 56 kg N/ha-yr and of mixed hay systems at half this amount (28 kg N/ha-yr). Soybeans fixed about two-thirds of the N they remove (Johnson, Welch and Kurtz, 1975).

The rate of nonsymbiotic N fixation in various ecosystems was estimated by Burns and Hardy (1975) as follows: cropland, 5 kg N/ha-yr; grassland, 15 kg N/ha-yr; forests, 10 kg N/ha-yr. Fixation in wetlands and surface waters was estimated at 20 kg N/ha-yr and includes fixation in sediment as well as that by algae in the water (Macgregor and Keeney, 1975).

Precipitation

A recent survey of N in precipitation in Wisconsin (Hoeft, Keeney and Walsh, 1972) gave a weighted average flux of 3.5 kg NO_3-N, 3.5 kg NH_4-N, and 7.5 kg particulate N (total N minus inorganic N) per hectare per year. Particulate N is assumed to be derived largely from windblown soil material, and thus its net contribution is zero. Undoubtedly some of the N in precipitation comes from agricultural activities through volatilization from fertilizers and manure. In this sense, the estimated inputs of nitrogen in Wisconsin precipitation involve some double accounting (that is, an input is counted twice).

Total Inputs

Total inputs of N for various Wisconsin land uses in 1974 are summarized in Table 3. Agriculture (categories 1-5) received 585×10^6 kg N/ha-yr, with 21 percent from precipitation, 62 percent from biological fixation, and 10 percent in feed supplements.

NITROGEN REMOVAL BY CROPS AND NITROGEN TRANSFERS

Nitrogen removal by nonleguminous crops in Wisconsin was calculated on the basis of N contents of various crops (Agricultural Research Service, 1971; Boone and Welch, 1972; Welch, 1972) and on the basis of reported yields (Wisconsin Agricultural Statistics, 1975). An estimated 144×10^6 kg of N were removed in 1974 (Table 4).

Some of the crop N is transferred out of the state in grain and vegetables and in animal products; some is used in the state and reappears in the production of wastes by the animal and human populations. A large amount of protein concentrate is imported. Estimates for these N transfers are given in Tables 4 and 5.

ANALYSIS OF INPUT, OUTPUT AND TRANSFER ERRORS

Of the N inputs listed in Table 3, the quality of the estimates of fertilizer and precipitation sources can be considered good. In contrast, there is undoubtedly some error in the estimates of symbiotic and nonsymbi-

TABLE 3. Estimated nitrogen inputs to Wisconsin, 1974.

Land use	10^3 ha	Source of nitrogen (10^6 kg N)[a]			
		Nitrogen fixation	*Fertilizer*	*Import of feed supplements*	*Inorganic nitrogen in precipitation*
Grain, cereals, potatoes	2,025	10	115	—	14.0
Alfalfa, mixed hay	1,600	316	0	60	11.0
Soybeans	88	4	0	—	0.6
Specialty crops	99	2	12	—	0.7
Pastures	1,795	27	0	—	13.0
Forest and idle land	7,573	76	0	—	53.0
Urban	200	1	0	—	1.4
Wetlands and water	1,260	26	0	—	9.0
Total	14,640	462	127	60	103
Total nitrogen added		752×10^6 kg/yr			

[a] From estimates in Welch (1972), Burns and Hardy (1975), Johnson et al. (1975), and Wisconsin Agricultural Statistics (1975).

TARLE 4. Nitrogen transfers for Wisconsin farm products, 1974[a].

Product	*Annral production as N*	*Transfers*			*Residual in soil*
		Within state	*Exports*	*Total*	
	10^6 kg N				
Crop products (nonlegumes)					
Corn grain	65	40	14	54	11
Corn silage	31	31	0	31	0
Small grains	30	23	4	27	3
Specialty crops	6	3	2	5	1
Pasture	27	27	0	27	0
Total	159	124	20	144	15
Crop products (legumes)					
Alfalfa	317	238	0	238	79
Soybeans	6	6	0	6	–2
Total	323	246	0	246	77
Animal products					
Dairy	68	13	55	68	—
Eggs	10	5	5	10	—
Meat	19	18	1	19	—
Feeding & breeding livestock	5	0	5	5	—
Total	112	36	66	102	—

[a] Estimates from Agricultural Research Service (1971), Boone and Welch (1972), Welch (1972), Wisconsin Agricultural Statistics (1975). Corn grain, 138 kg N/1,000 kg; corn silage, 3.3 kg N/1,000 kg; sweet corn, 35 kg N/1,000 kg; wheat, 31 kg N/1,000 kg; barley and rye, 18 kg N/1,000 kg; oats, 20 kg N/1,000 kg; potatoes, 2.8 kg N/1,000 kg.

TABLE 5. Nitrogen as human or animal wastes produced annually in Wisconsin.

Producer	*Population (millions)*	*kg N/yr per unit*[a]	*Total produced (10^6 kg N)*
Humans	4.6	6.0	28
Cattle	4.64	52.0	240
Swine	1.40	7.0	10
Sheep	0.10	9.0	1
Chickens			
Laying	6.8	0.6	4
Broilers	11.3	0.2	2
Turkeys	4.6	0.4	2
Total			287

[a] From estimates in National Research Council (1972) and Taiganides and Stroshine (1971).

otic N fixation. However, inputs from nonsymbiotic N fixation are relatively small, particularly in the agricultural sector. Inputs from symbiotic fixation have been estimated from data on crop harvests (Table 2). Fixation of N by alfalfa is by far the largest component of such inputs. A range of ±10 percent in the N content of alfalfa is likely in practice, giving a range in removal of 197 ± 20 × 10^6 kg N. A further source of error is the allocation of residual N from alfalfa, an important value because it affects the size of the pool of available N in the balance, as discussed later. Alfalfa also takes up some N from the soil; accounting for this transfer would reduce the net value of the contribution by legumes through fixation. The estimate used in Table 2 is based on observation of the relative yield response of corn and alfalfa fields the first year after plowing. The actual value will depend on weather and farm management practices and it is therefore difficult to estimate possible error.

Nitrogen production and transfer estimates (Table 4) were made by multiplying accepted values for the N content of each product by the appropriate production, consumption, or export data, available from Wisconsin Agricultural Statistics (1975). Similarly, N waste production values were obtained by multiplying accepted per-unit N excretion values by the populations. The N transfer and waste production values (Tables 4 and 5) are thought to be reliable, with the possible exception of the data for pastures (Table 4), where N uptake was equated to N fixation. This estimate would be low if the N in the excreta of grazing cattle were considered, and high if considerable immobilization of N were occurring in the topsoil. On balance, the estimate seems low, since uptake of 22 kg N/ha (40 × 10^6 kg N/1.8 × 10^6 ha of pastureland; Tables 3 and 4) is equivalent to the production of only about 1500 kg (1.5 percent N in herbage)/ha of dry matter. However, since extensive data on the productivity of Wisconsin pastures are lacking, no better estimates are available.

AGRICULTURAL NITROGEN BALANCE IN WISCONSIN

Estimates of the sizes of pools and fluxes of N in Wisconsin agriculture are presented in Figure 2. Two models were examined for their applicability in this exercise. One involved consideration of the total soil N as the receptor of the annual N flux, assuming steady state in this pool. The pool of organic N in the soil in Wisconsin was estimated, assuming 0.15 percent N (4000 kg N/ha in 20 cm of soil), for a total of 22,500 × 10^6 kg N. This pool is several orders of magnitude larger than any of the N inputs (see Table 3 and Fig. 2). Thus, the steady-state assumption with respect to soil organic N would have to be extremely accurate to permit estimation of an output by difference (Kohl, Shearer and Vithayathil, 1977).

The problem can be overcome in part by considering the pools of available N and slowly-available organic N in the soil to be dynamic. The steady-state assumption can be applied with greater accuracy to the soil available N pool because this would not be expected to vary markedly on an annual basis. This pool, which is essentially the inorganic N in the root zone, also is of the same magnitude as the annual N fluxes. Experi-

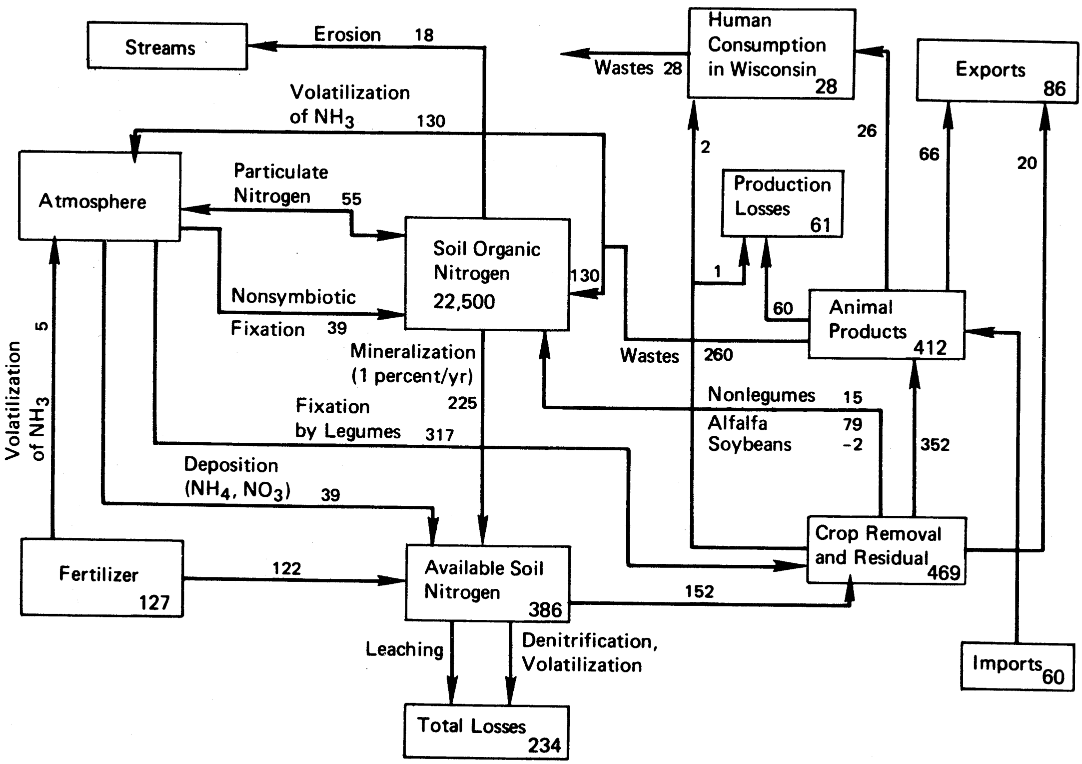

Fig. 2. The flow of nitrogen in Wisconsin agriculture in 1974. Pool sizes and fluxes are expressed in 10^6 kg N.

ence has shown, however, that the main problem with the latter approach is in estimating the net mineralization from the soil organic N pool. This is particularly true in respect to the assignment of mineralization (availability) rates of crop residues and manure, two major inputs to the Wisconsin agricultural N budget.

Rather than assign separate mineralization values to various inputs of organic N, I treated them as an integral part of the soil pool of organic N, and estimated a mineralization rate for this pool. It was assumed that inputs of organic N from crop residues and manure are small relative to the total pool of organic N in the soil. Net mineralization of N from the organic pool is normally considered to range between 1 and 3 percent a year (Bremner, 1967). Under the cool temperate conditions in Wisconsin, the lower value is probably more realistic. Thus, net mineralization was estimated at 225×10^6 kg N/yr. Other inputs to the soil pool of available nitrogen are 39×10^6 kg N/yr from the atmosphere and 122×10^6 kg N/yr from fertilizers.

The organic N input from manures was estimated at 130×10^6 kg N/yr assuming 50 percent loss from volatilization (Frere, 1976). Total annual input from plant residues was estimated at 94×10^6 kg N, and nonsymbiotic fixation was estimated at 39×10^6 kg N/yr. The total input of organic nitrogen was thus 263×10^6 kg N/yr. Nitrogen outputs by erosion to streams were estimated at 3 kg N/ha-yr (Shrader and Pierre, 1966), for a total loss of 18×10^6 kg N/yr by that route. Although inputs to and outputs from the pool of organic N are nearly balanced, unknown errors in the assumptions are too great to determine net gain or loss in this pool.

The uptake of N from the pool of available N in soil was estimated at 152×10^6 kg N/yr, or 39 percent of the total flux (386×10^6 kg N/yr) in that pool. The value was obtained by the difference between the total for removals and residual N, and the estimate for fixation by legumes. This estimate is reasonably close to the 50 percent value commonly cited for overall efficiency of N uptake by crops, especially considering that 1974 was a year of relatively poor corn harvests. The remainder of the total flux, 234×10^6 kg N/yr, or 42 kg N/ha-yr, is assumed to be lost to the environment by leaching and denitrification, but present data do not permit apportioning this loss between the two routes. Furthermore, an analysis of potential errors in estimates is difficult. If the estimate of the pool of organic N were in error by ± 10 percent, and if actual net mineralization ranged from 1 to 1.5 percent, the per hectare loss of nitrogen would range from 36 to 66 kg/yr. This loss seems high and could be the result of overestimation of the rate of mineralization of soil organic N, or of underestimation of the amount of inorganic N taken up by legumes. The high degree of aggregation also limits the usefulness of the model, which reveals little about possible site-specific problems (e.g., much of the agriculture is in the fertile lands in the southern part of Wisconsin).

Most of the crop N is transferred to animals, and the majority of this N is transferred to wastes (Fig. 2). Volatilization is estimated to be a major loss of N from the system. This output has not been balanced by an equivalent atmospheric input, because some of this ammonia is deposited on non-agricultural lands and some is transferred by the prevailing winds across the state boundary.

Human consumption of grain and meat, and exports from the state, account for 114 $\times 10^6$ kg N (27 percent of the harvested plant N). Human waste production (Table 5) does not equate exactly with the estimated consumption of food N (Fig. 2). The difference may be the result of losses in food preparation, or of errors in estimates of the transfer functions. The amount of N in human wastes that is now deposited on land in Wisconsin is negligible.

The N in the animal products compartment is partitioned into wastes and edible products. Fifty-six percent of the total (260 $\times 10^6$ kg N) was estimated to be transferred as wastes. Production losses, the unaccounted for portion of the animal products pool, represent about 14.6 percent of the total (60×10^6 kg N). This value seems high, and suggests some errors in the analysis.

Summary and Conclusions

Because Wisconsin is largely a rural state, the N mass balance is dominated by agriculture. However, it differs from the Corn Belt states in that the major N input is from symbiotic N fixation by legumes in association with the livestock (primarily dairy) industries. Of the 585×10^6 kg of N estimated to be cycled in Wisconsin agriculture in 1974, fertilizer N supplied 22 percent, N fixation 61 percent, and atmospheric N 7 percent. Crops remove about 65 percent of the total N cycled, and a major portion of this N estimated at about 68 percent, reappears as animal wastes.

Despite some of the large uncertainties, several interesting points emerge from this mass balance. For example, in good crop years corn production required more N than was added to the soil while in poor years, excess fertilizer N was added. The model does point out that about twice as much N is imported into the state as is exported in food and feed products, and that better utilization of manure and legume residue N might help bring imports more in balance with exports. The use of an "available soil N" pool indicated that the system is relatively more responsive to fertilizer N than the proportion of fertilizer N input to agriculture would indicate. Hence, a doubling in fertilizer use would more than double the losses of N in the system. However, it also indicates that at present fertilizer N does not appear to be causing a statewide pollution problem.

Acknowledgments

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PRELIMINARY REPORTS ON THE FLORA OF WISCONSIN NO. 68. CAPRIFOLIACEAE—HONEYSUCKLE FAMILY

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Department of Botany
University of Wisconsin-Milwaukee

An earlier study (Wade & Wade, 1940) described the food and cover values for wildlife and the distribution of the native species of the Caprifoliaceae. This study expands that work by including descriptions of the native and adventive genera and species, updating the nomenclature and distribution records, supplying additional habitat information and including keys to the identification of various taxa. Most of this information was compiled from specimens in the herbaria of the University of Wisconsin-Madison (WIS), University of Wisconsin-Milwaukee (UWM), Milwaukee Public Museum (MIL), University of Minnesota (MIN), University of Wisconsin-Oshkosh (WSO), University of Wisconsin-LaCrosse (UWL) and the University of Wisconsin-Stevens Point (UWSP). Other sources are cited in the text.

Dots, triangles and crosses on the maps indicate exact locations where specimens have been collected. The numbers within the map corner inserts indicate the number of specimens noted which were flowering or fruiting in the respective months and indicate when the species may be expected to flower or fruit in Wisconsin. Specimens in vegetative conditions, in bud or with immature fruits were not included. The nomenclature and descriptive features generally follow Gleason and Cronquist (1963) and Fernald (1950); however, more recent taxonomic treatments of certain taxa are discussed in the text or cited in the bibliography.

Grateful acknowledgment is made to the curators of the above herbaria for the loan of specimens; to many of my students who supplied additional specimens for examination; and to Dr. Hugh H. Iltis for his suggestions in the preparation of this report as well as his critical reading of the manuscript.

CAPRIFOLIACEAE A. L. DE JUSSIEU HONEYSUCKLE FAMILY

Upright, climbing or trailing shrubs or rarely perennial herbs (*Triosteum*) with opposite, simple or compound, mostly exstipulate (except in *Sambucus* and *Viburnum*), deciduous or sometimes evergreen leaves. *Flowers regular or irregular, epigynous, perfect or rarely sterile, subtended by 2-4 bracts or bracteoles,* in corymbs, cymes, in spike-like whorls at the tips of branches or in pairs in the axils of leaves. Calyx of 3-5 small or tooth-like sepals. Corolla gamopetalous, 3-5 lobed, rotate, tubular or campanulate, sometimes gibbous near the base and often bilabiate. Stamens 4-5, epipetalous, alternating with the corolla lobes; filaments long or short; anthers oblong or linear, longitudinally, dehiscent and versatile. *Ovary inferior, 2-5-locular* with 1-many seeds (stones) per locule.

A family of 18 to 20 genera and about 500 species, chiefly of the North Temperate Zone, with many species in eastern Asia and eastern North America and several species ranging southward in mountainous areas to South America, Australia and New Zealand.

In two regional floras (Fernald, 1950; Gleason & Cronquist, 1963), the family Caprifoliaceae is included, with the morphologically similar and largely tropical family Rubiaceae, in the order Rubiales. Some authors have suggested uniting them into one family; however, Ferguson (1966) listed several problems of such a union.

Hillebrand and Fairbrothers (1969, 1970a, and 1970b) have concluded, from serological investigations, that some genera of the Caprifoliaceae (*Sambucus* and *Viburnum*) are more closely related to the genus *Cornus* (Cornaceae) than to other genera of either the Caprifoliaceae or Rubiaceae. In the classification systems proposed by Cronquist (1963), Takhtajan (1969) and Thorne (1968), the Caprifoliaceae is placed in the order Dipsacales, which also includes the families Adoxaceae, Valerianaceae, Dipsacaceae and Calyceraceae. More detailed investigations are needed on the relationships of these families and this report will not include the Caprifoliaceae in a specific order.

Key to Genera

A. Corolla rotate or nearly so, regular; style very short or absent; stigmas 3 or 3-lobed.
- B. Leaves pinnately compound; fruit berry-like with 3 stone-like seeds. . . . . .1. SAMBUCUS.
- BB. Leaves simple; fruit a drupe with 1 stone-seed . . . . .2. VIBURNUM.

AA. Corolla campanulate, funnelform or tubular, often more or less irregular or bilabiate; style elongate; stigma capitate.
- C. Herbaceous perennials; flowers sessile in the axils of cauline leaves. . . . . .3. TRIOSTEUM.
- CC. Shrubs or woody vines; flowers in corymbs, cymes, whorled spikes or pedicelled in pairs in the axils of cauline leaves.
  - D. Trailing or creeping shrubs, slightly woody at the base; stamens 4. . . . . .4. LINNAEA.
  - DD. Erect shrubs or climbing woody vines; stamens 5.
    - E. Corolla campanulate; ovary 4-locular; fruit a 2-seeded berry. . . . . .5. SYMPHORICARPOS.
    - EE. Corolla funnelform, tubular or bilabiate; ovary 2-5-locular; fruit fleshy or dry, several seeded.
      - F. Fruit a capsule, with persisting calyx lobes; leaves serrate. . . . . .6. DIERVILLA.
      - FF. Fruit a berry, with short or non-persisting calyx lobes; leaves entire. . . . . .7. LONICERA.

Tribe SAMBUCEAE HBK. ex DC.

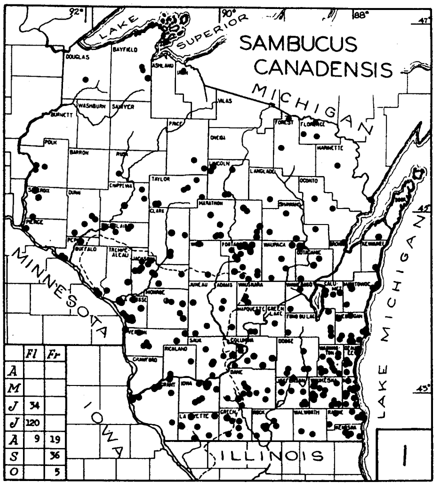
1. SAMBUCUS L. Elderberry

Tall shrubs or small trees, often spreading from root sprouts, with grayish, sometimes warty, bark and *stems with large piths. Leaves pinnately or rarely bipinnately compound,* with serrate leaflets and sometimes having small stipules or glands at the bases of the petioles. Flowers small, whitish, regular in terminal bracteolate compound cymes or panicles. Calyx of 5-teeth, or nearly absent. Corolla rotate, 5-lobed, with a short tube. Stamens 5, inserted near the base of the corolla; filaments slender, short; *anthers short, oblong, extrorse.* Ovary 3-5-lobed. Fruit a drupaceous berry containing 3-5 stone-like seeds.

A genus of about 20 species, widespread in the North Temperate Region; approximately ten species occurring in North America, including several introduced from Eurasia. The two species native in Wisconsin may be distinguished as follows:

Key to Species

A. Flowers in flat-topped umbelliform cymes; pith white; fruits black. . . . . .1. S. CANADENSIS.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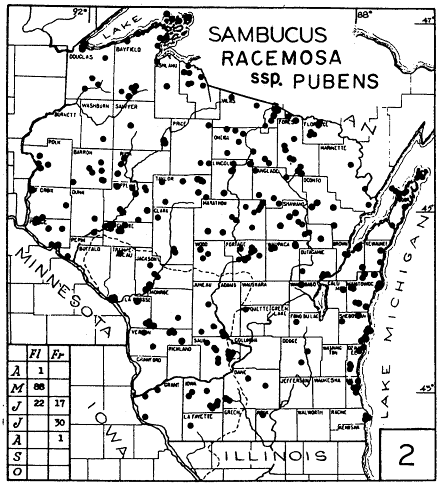
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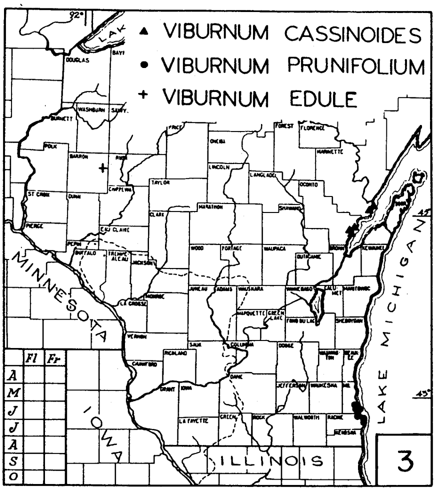
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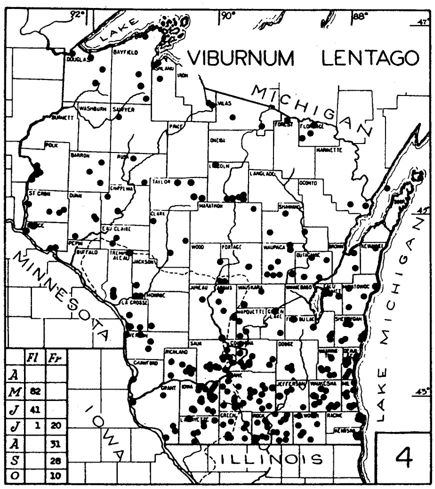
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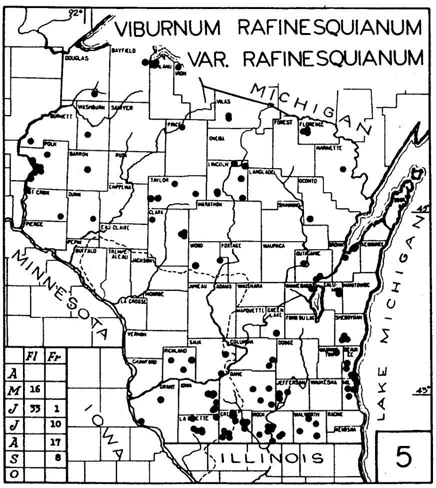
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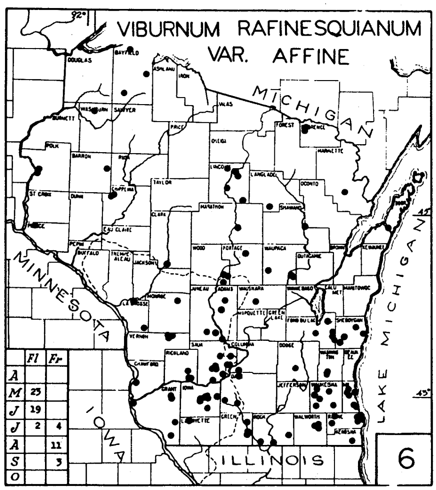
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1. SAMBUCUS CANADENSIS L. var. CANADENSIS Common Elder Map 1.

Shrub up to 4 m tall, readily sprouting from the roots and bearing *flowers and fruits in flat-topped terminal cymes,* 10-20 cm broad. Stems and branches with grayish-brown, smooth to slightly rough bark and *large white pith. Leaves pinnately compound; leaflets 5-11,* lanceolate to elliptic, 5-15 cm long and 3-6 cm wide, sharply serrate, acuminate at the tips and with rounded bases, short-stalked, essentially glabrous on both surfaces or sometimes hirtellous on the veins beneath. Flowers white, rotate, 5-6 mm wide, fragrant. *The drupaceous berries purplish-black* (rarely red, yellow, orange or green), 5-6 mm in diameter, with 3-5 (usually 4) stone-like seeds. Ripe fruits are used for making pies, pancakes, jellies and wine. 2N = 36.

Widespread in Wisconsin on moist or damp soils bordering upland woods, edges of swamps and bogs, in sedge meadows, along banks of streams and lakes and in lowland woods. Less common in mesic or dry deciduous or coniferous woods, especially in northern and northwestern counties. It is widely planted as an ornamental in parks, yards and along fencerows. A number of horticultural varieties have been described (Bailey, 1949) based on variations in fruit color, leaf color and dissection of leaves. The var. *laciniata Gray,* which should be more appropriately designated as a form, often escapes to railroad embankments and waste areas. Pith of this species is often used in botanical laboratories for holding specimens in preparation for freehand sectioning. Flowering chiefly from mid-May to August; fruiting in August to October.

2. SAMBUCUS RACEMOSA L. subsp. PUBENS (Michx.) Hulten Red-berried Elder Map 2.

Sambucus pubens. Michx.

Sambucus racemosa L. var. *pubens* Wats.

Tree-like shrub, up to 3 m tall, with flowers and fruits in *paniculate inflorescences. Stems grayish with warty bark, brown pith and finely pubescent twigs. Leaves pinnately compound; leaflets 5-7,* ovate-lanceolate to narrowly oblong, 5-12 cm long and 2-6 cm wide, with finely serrate margins, acuminate tips and rounded bases and more or less downy pubescent beneath. Flowers yellowish-white, ill-scented, similar in size and form to *S. canadensis.* Fruits *bright red* (sometimes greenish, white or yellow) *drupaceous berries* with 3-5 stone-like seeds; edible when ripe. 2N = 36.

Fernald (1950) and Gleason and Cronquist (1963) list this shrub as a distinct species, *S. pubens* Michx., although the latter authors suggest it may be considered a variety of the Eurasian species, *S. racemosa* L. Hulten (1970) investigated the Asian, European and American taxa and concluded they should be considered as subspecies of one polymorphic species. His treatment is followed in this report.

Variations in dissection of leaves, pubescence and color of flowers and fruits have been given varietal or forma designations and are listed in Bailey (1941) and Fernald (1950). Several specimens with finely dissected leaves (f. *dissecta* (Brit.) Fern.) were noted in several herbaria, but were too few in number to be mapped.

Native to the boreal and northern hardwood forests of North America (Newfoundland and New England to Alaska, southward to Oregon, South Dakota, northeastern Iowa, northern Illinois and Indiana and in the eastern uplands to Tennessee and Georgia). In Wisconsin it is more common northward in open conifer woods, mixed conifer-deciduous forests, rich maple woods and at the bases of rocky bluffs and along stream banks, southward it occurs infrequently in ravines and along cool stream valleys in the southeast and along moist stream banks and cool slopes on sandstone bluffs and in rocky woods in central and southwestern Wisconsin. Flowering late-April to early-June; *fruiting mid-June to early-August.*

Two European species, *S. nigra* L. and

S. Ebulus L. have been introduced into eastern North America and have been reported as becoming established along roadsides and in waste areas; however, no specimens have been noted in any Wisconsin herbarium.

Tribe VIBURNEAE Fritsch

2. VIBURNUM L. Viburnum

Deciduous (some introduced species are evergreen) erect or decumbent shrubs or small trees. Leaves simple, opposite or rarely whorled, entire, serrate, dentate or lobed, glabrous or pubescent (sometimes with stellate hairs), petioled, exstipulate or stipulate (some stipules reduced to glands). Flowers perfect or occasionally sterile, regular, subtended by cauducous bracts and bracteoles, in terminal or axillary compound cymes or panicles. Calyx of 5 tooth-like lobes, persistent. Corolla rotate to broadly campanulate, 5-lobed, white or sometimes pinkish. Stamens 5, inserted near the base of the corolla; filaments slender; anthers oblong, 4-lobed introrse. *Ovary 3-locular, only one fertile with a single pendulous ovule;* style short; stigma 3-lobed. *Fruit a globose or ellipsoid, 1-seeded drupe, topped by the persistent calyx.*

Chiefly a North Temperate Zone genus of about 250 species of which 25 are native to North America. Three or four Asian and European species have become naturalized. This complex genus has been divided into nine sections based on the shape and furrowing of the stone-seeds, winter buds and leaf venation. Wisconsin species are included in the sections: *Lantana* Spach, *Lentago* (Raf.) DC., *Odontotinus* Rehder and *Opulus* DC. Many of the species are widely planted as ornamentals in city, county and state parks, home yards, arboretums and botanical gardens. A detailed list of cultivated species in the University of Wisconsin Arboretum was compiled by Wood (1976). Fruits of most species are eaten by a variety of birds and wildlife.

Key to Species

A. Leaves pinnately veined, not lobed.
- B. Leaves entire, wavy-margined or finely serrate, the lateral veins curved and branching near the margins, not terminating in the teeth; buds naked or with one pair of scales.
  - C. Lower surfaces of leaves and branchlets stellate-pubescent; winter buds naked. . . . . 1. V. LANTANA.
  - CC. Lower surfaces of leaves and branchlets glabrous or scurfy, not stellate pubescent; winter buds with one pair of scales.
    - D. Inflorescence definitely peduncled; margins of leaves entire, undulate to crenate. . . . . 2. V. CASSINOIDES.
    - DD. Inflorescence sessile or nearly so; margins of leaves serrate or serrulate with sharp teeth.
      - E. Leaves mostly with sharp acuminate tips; branchlets slender and whip-like. . . . . 3. V. LENTAGO.
      - EE. Leaves with acute, obtuse or nearly rounded tips; branchlets stiff, often nearly at right angles to the main branches. . . . . 4. V. PRUNIFOLIUM.
- BB. Leaves dentate, the lateral veins straight or with only 1-2 branches and terminating in the teeth; buds with 2 pairs of scales. . . . . 5. V. RAFINESQUIANUM.

AA. Leaves palmately veined and, except for the uppermost pairs, mostly palmately lobed.

F. All flowers perfect, regular; petioles without stipules or glands.

G. Leaves stellate-pubescent beneath; drupes blue-black ....6. V. ACERIFOLIUM.

GG. Leaves glabrous or with only simple hairs beneath; drupes yellow-orange to red. ....7. V. EDULE.

FF. Marginal flowers sterile, with enlarged and more or less irregular corollas; petioles with stipules at the bases and glands at the summit.

H. Glands at the tips of the petioles stalked and round-topped; stipules with thickened tips. ....B. V. TRILOBUM.

HH. Glands at the tips of the petioles sessile or nearly so, cup-shaped; stipules filiform with slender tips. ....9. V. OPULUS.

SECTION LANTANA SPACH

1. VIBURNUM LANTANA L. Wayfaring Tree

Shrub, up to 5 m high, with *cinerous-stellate pubescent branchlets and naked winter buds.* Leaves broadly ovate, oblong-ovate to nearly oval, 5-12 cm long and nearly and broad, acute or obtuse at the tips and rounded to cordate at the bases, the margins finely serrate and both surfaces stellate-pubescent; petioles 1-2 cm long, pubescent. Flowers perfect, white, 4-18 mm wide, in short-peduncled cymes about 5-10 cm broad; stamens exceeding the corolla lobes. Fruits flattened, ovoid drupes, 8-10 mm in diameter, red but becoming dark purple-black at maturity. 2N = 18.

Introduced from Eurasia and commonly planted in home yards, parks and other landscaped areas; frequently escaping to adjacent open woods, roadsides and along fencerows. Because few specimens outside of cultivation were noted in the various herbaria, the extent of naturalization in Wisconsin could not be mapped. Flowering May-June; fruiting late August to September. *V. carlesii* Hensl. (Carleś Viburnum), which differs in having fragrant salverform flowers and leaves with more widely spaced serrations, is often planted as an ornamental and may occur in similar habitats.

SECTION LENTAGO (RAF.) DC.

2. VIBURNUM CASSINOIDES L. Witherod; Wild Raisin Map 3 (triangles).

Shrub, up to 4 m tall, with smooth to *brownish-scurfy branchlets and winter buds covered by a pair of connate, yellow or golden scurfy scales.* Leaves lanceolate, ovate, obovate to oval, 3-12 cm long and 2-6 cm wide, on scurfy petioles, the tips short-acuminate, bases rounded to tapering, *margins subentire to crenate,* pinnately veined with the lateral veins curved and branching near the margins. Flowers perfect, white, ill-scented, with exserted stamens, in cymes 3-10 cm broad, on peduncles 0.5-2 cm long. Drupes flattened-ovoid to nearly subglobose, 8-10 mm in diameter, blue-black, but often appearing bluish because of dense bloom. 2N = 18.

Native to the northern hardwood forests of eastern North America, reaching its western limit in upper Michigan and northeastern Wisconsin where it occurs at the margins of moist woods, damp clearings and in damp or swampy shrubby areas. Wisconsin collections are only from Marinette and Oconto Counties. None of the herbarium specimens had flowers and only two had fruits, hence flowering and fruiting times are assumed to be similar to those of other Viburnums.

3. VIBURNUM LENTAGO L. Nannyberry; Sheepberry Map 4.

Tall shrub or small tree, up to 10 m, *with slender whip-like, ascending branchlets.* Winter buds slender-conical, 1-2 cm long, those with floral primordia with swollen bases, *enclosed by a pair of valvate, gray-scurfy scales.* Leaves ovate, elliptic-lanceolate to oblong, 5-10 cm long and 3-6 cm wide, on *wavy-margined petioles* 1-3 cm long, exstipulate, glabrous on both surfaces or sometimes reddish-scurfy on the veins beneath, *lustrous above,* the margins sharply serrulate, usually with sharply acuminate tips and acute to rounded bases, and the lateral veins curved and anastamosing before reaching the margins. Cymes sessile or on short peduncles (rarely exceeding 1 cm), 5-12 cm broad; flowers perfect, white, fragrant with exserted stamens. Fruits blue-black, glaucous, globose to ellipsoid drupes, 8-15 mm long, often persisting throughout the winter. 2N = 18.

Common throughout Wisconsin in moist borders of upland woods, in open floodplain woods, copses, thickets bordering swamps and bogs and on wooded lake and stream banks and seepage slopes; less common in dry upland woods, dry bluffs, roadsides and pastured woods. It is frequently planted as an ornamental in parks and to attract birds in home yards. Flowering mid-May to mid-June; fruiting July to October.

4. VIBURNUM PRUNIFOLIUM L. var. PRUNIFOLIUM Black Haw
Map 3 (dots).

Coarse shrub, up to 8 m tall, *with stiff branchlets, often nearly at right angles to the main branches,* the lower ones nearly thorn-like. Winter buds similar to *V. lentago,* but mostly 5-13 mm long and with *reddish-scurfy scales.* Leaves ovate, obovate-oblong to broadly elliptic, 3-10 cm long and 2-6 cm wide, on slightly margined petioles (0.5-2 cm long), exstipulate, the dull subcoreaceous blades with acute to rounded (rarely acuminate) tips and rounded to cuneate bases, serrulate margins, glabrous but sometimes pubescent with reddish scurf beneath and the less prominant lateral veins curving and branching near the margins. Cymes sessile or nearly so, 3-12 cm broad, the flowers white, perfect, slightly scented. Fruits blue-black, elliptical drupes, 7-15 mm long, persistent into the winter. 2N = 18.

Native to the deciduous forest region of eastern North America, reaching its westward limit in southeastern Wisconsin. The few Wisconsin specimens were collected in thickets and along margins of maple-beech woods in Milwaukee and Racine Counties. Absence from Kenosha County is probably the result of inadequate collecting. This shrub is often planted as an ornamental in horticultural gardens. Flowering and fruiting times are similar to those of *V. lentago.*

SECTION ODONTOTINUS REHDER

5. VIBURNUM RAFINESQUIANUM Schultes
Downy Arrowwood

Shrub, 1-3 m tall, with many branches from the base, the bark smooth, dark gray and the twigs yellow-brown. Winter buds with *two pairs of overlapping scales.* Leaves short-petioled, stipulate, the blades ovate, oblong-ovate to suborbicular, 2.5-10 cm long and 1-6 cm wide, with acute to acuminate tips and obtuse to subcordate bases, the *lateral veins straight or sometimes forking and extending to the 4-10 coarse dentations on each margin,* the upper surfaces glabrous or sparsely pubescent, the lower surfaces downy at least on the veins with both simple and stellate hairs. Cymes 1.5-7 cm broad, with 4-7 branches; flowers on pedicels 0.5-3.5 cm long, perfect, white, the corolla lobes rounded to sub-acute and finely serrate on the margins, only slightly recurved; hypanthia glandular. Fruits purplish-black, flattened, ellipsoid drupes, 6-9 mm broad. 2N = 36. Two varieties have been described, both occurring in Wisconsin:

5a. VIBURNUM RAFINESQUIANUM Schultes var. RAFINESQUIANUM Map 5.

Leaf blades pilose beneath; petioles 3-8 (mostly less than 7) mm long, often exceeded by the stipules. General distribution is from Vermont and southern Quebec to Manitoba, southward to Georgia, Kentucky and Missouri. Widespread throughout Wisconsin, in similar habitats, but more common, than the following variety.

5b. VIBURNUM RAFINESQUIANUM Schultes var. AFFINE (Bush) House Map 6.

Leaf blades glabrous beneath, except pilose on the veins or in the axils of the veins; petioles 5-12 (mostly about 10) mm long, usually longer than the stipules. Range extends from southern Ontario to Minnesota, southward to Virginia and Arkansas.

Intermediates with short petioles and sparsely pubescent blades or with long petioles and pubescent blades occasionally occur. Although var. *affine* is less common, both varieties are widespread in habitats ranging from dry to moist deciduous and northern hardwood stands, on rocky, sandy and ravine slopes, in thickets along fence-rows, along power line right-of-ways and sometimes in dry, open or pastured oak woods and in clearing. Flowering mid-May to late-June; fruiting mid-July to late-September.

Two other species in this section often planted as ornamentals are: *V. molle* Mich. (Kentucky Viburnum), with long-petioled (2 cm or more) and deeply cordate leaves and *V. dentatum* L. (Southern Arrow-wood) with long-petioled leaves with rounded bases. The hardiness and the extent of establishment outside of cultivation of these species is not known.

6. VIBURNUM ACERIFOLIUM L. var. ACERIFOLIUM Maple-leaved Viburnum; Dockmackie. Map 7 (dots).

An erect, slender-branched shrub, 1-2 m tall, the branches upright, pilose at first becoming glabrate, and with scaly winter buds. Leaves elliptic to nearly orbicular, palmately veined, usually 3-lobed (rarely lobeless), 4-12 cm long and nearly as wide, with acute to acuminate tips, coarsely serrate to toothed margins and rounded to cordate bases, the upper surfaces glabrous to sparsely pubescent, *the lower surfaces downy with stellate pubescence and numerous reddish or black dots;* petioles 0.8-4 cm long, pilose to nearly glabrous; *stipules sometimes present.* Cymes 2.5-8 cm broad with white or pinkish flowers. Fruits purple-black (rarely white), ellipsoidal to globular drupes, 5-10 mm in diameter. 2N = 18.

Plants with pink flowers have been designated as f. *collinsii* Rouleau, those with white fruits as f. *eburneum* House and those with ovate, unlobed leaves as f. *ovatum* Rehd. Only f. *ovatum* has been observed sufficiently to be plotted (crosses) on Map 7.

Common in northern and central Wisconsin in mature northern hardwood forests, maple-beech-basswood forests and sometimes in jack pine stands, second-growth aspen and birch woods, on wooded talus slopes and rocky outcrops and in wooded ravines along the Lake Michigan shoreline. It is less common in southern Wisconsin in maple-basswood and oak woods. The absence of specimens in the westernmost counties indicates that this species probably reaches its western limit here. Rosendahl (1955) does not list this species for Minnesota. Flowering late-May to early-July; fruiting late-July to October.

SECTION OPULUS DC.

7. VIBURNUM EDULE (Michx.) Raf. Squashberry Map 3 (crosses).

An erect or straggling shrub, 0.5-2 m tall, with grayish bark, *glabrous, reddish-brown, ridged branchlets* and winter buds with 2 connate outer scales. Leaves nearly orbicular, 3-11 cm broad, palmately-veined and shallowly 3-lobed or some unlobed, the margins coarsely serrate, the upper surfaces glabrous, the lower surfaces more or less pubescent on the veins and *sometimes with glands above the junction with the petioles;* petioles exstipulate, 1-3 cm long. Cymes 1-3.5 cm broad, mostly 5-rayed, on short peduncles, bearing white, perfect flowers, 5-6 mm wide, with included stamens. Fruit a red or orange, ovoid to nearly globose drupe, 8-10 mm in diameter. Chromosome number not determined.

A boreal species which ranges from Labrador to Alaska, southward to New York, Ontario, northern Michigan and Minnesota and in the Rocky Mountains to Colorado and Oregon. It has been reported in only one locality in Wisconsin, at the base of a quartzite talus slope in the Barron Hills, near Leheigh in Barron County. The specimen cited was collected in 1933 and no other plants have been observed since; therefore, if it is not extinct it is one of the rarest plant species in Wisconsin. Flowering late-May to early-June; fruiting August to October.

8. VIBURNUM TRILOBUM Marshall American Highbush Cranberry; Pembina Map 8.

Viburnum opulus L. var. *americanum* Ait.
Viburnum opulus L. var. *trilobum* Marsh.
Viburnum opulus L. subsp. *trilobum* R. T. Clausen
Viburnum americanum of various authors, not Mill.

Coarse shrub or small tree, up to 4 m tall, with grayish bark and smooth branchlets bearing *reddish, ovoid, bluntly apiculate winter buds* which are enclosed by two connate scales. Leaves broadly ovate, 3-9 cm long and 3-6.5 cm wide, palmately-veined, 3-lobed, the lobes elongated and coarsely toothed and the bases obtuse, rounded or truncate, the upper surfaces glabrous or sparsely strigose, the lower paler and with scattered appressed hairs to nearly glabrous; petioles 1-2.5 cm long with *one or more pairs of stalked, round-topped glands at the tips and with one or two pairs of slightly clavate stipules at the bases.* Cymes 4-15 cm broad, on peduncles 2-6 cm long. Flowers white, perfect, 8-15 mm wide in the center of the inflorescence; sterile marginal flowers 15-18 mm wide, with slightly irregular corollas. Fruits orange to red, subglobose to ovoid pulpy drupes, 7-10 mm in diameter; edible and often used in jellies. 2N = 18.

Generally distributed throughout the state in poorly drained peaty soils, bogs, low swampy woods, moist alder thickets, edges of wet pastures and along moist stream and lake banks; infrequent on north-facing slopes, moist deciduous woods and mesic to dry wooded bluffs. Flowering May to June; fruiting July to September.

9. VIBURNUM OPULUS L. European Highbush Cranberry; Guelder Rose Map 9.

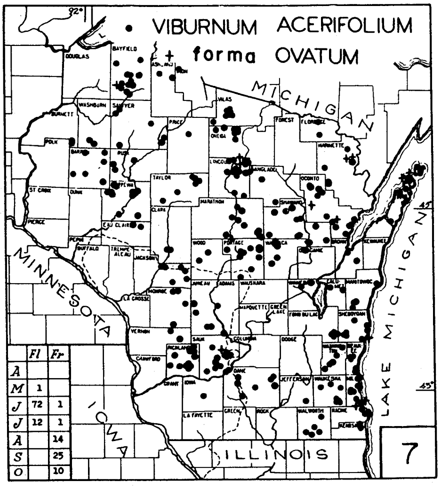
Viburnum opulus L. var. *opulus*

Similar to *V. trilobum* except the leaves are more rounded and the lobes less prolonged, *the petioles with sessile, concave-topped glands at the tips and the stipules are filiform or attenuate.* Fruits are more bitter and less pleasant to the taste than *V. trilobum,* often persisting through the winter. 2N = 18.

A horticultural variant, the snowball-tree, var. *roseum* L., with a rounded inflorescence and only sterile flowers, is sometimes planted as an ornamental.

This Eurasian species, frequently planted in parks, yards, botanical gardens and arboretums, has become established, probably through dispersal by birds, in open and pastured woods, along fencerows, in shrubby roadsides and in waste areas. The sparsity of records in the northern half of the state may be the result of limited collecting or the preference of botanists for the native species, *V. trilobum.*

The similarity in morphological features of *V. trilobum* and *V. opulus* is the reason some workers consider them as varieties or subspecies of *V. opulus.* Since no recent investigations have been carried out concerning actual or potential hybridization between them and because of distinguishing features of the petiolar glands, stipules, fruit taste, habitat preferences and their allopatric natural ranges, I have considered them to be distinct species.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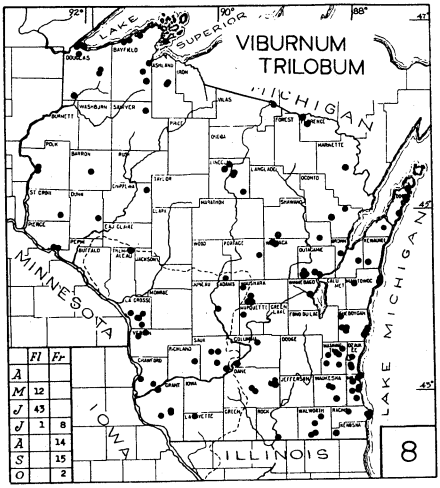
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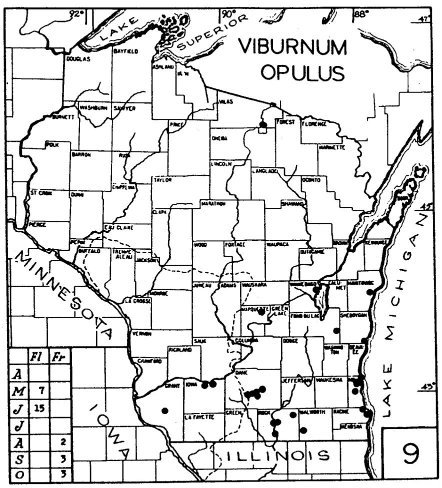
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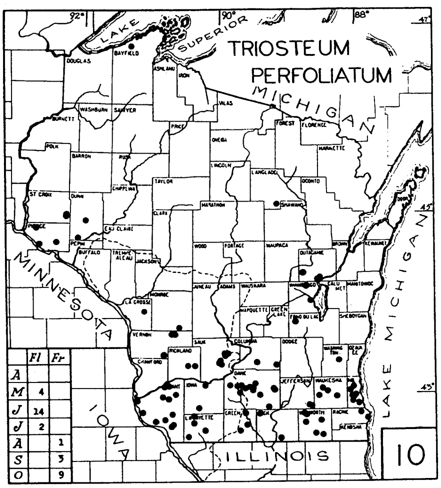
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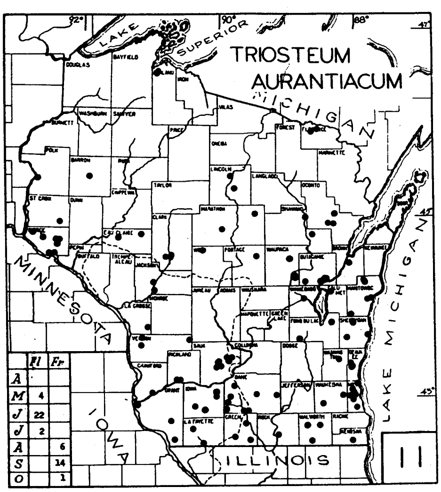
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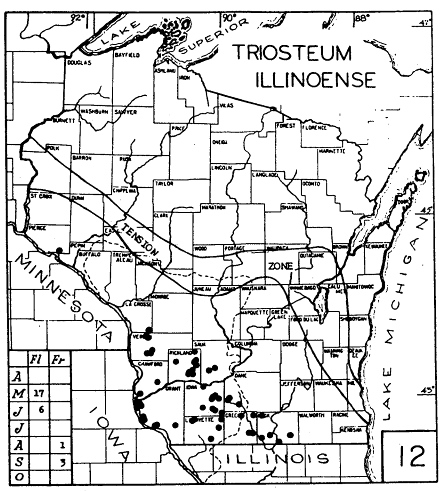
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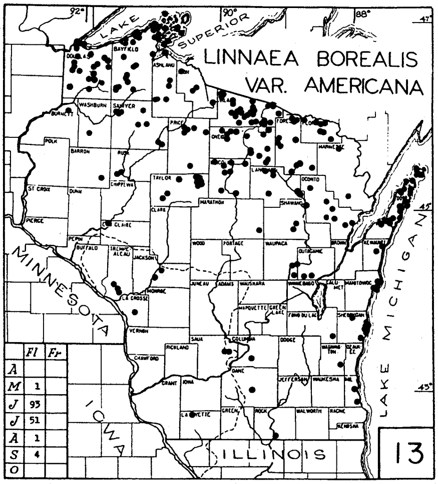
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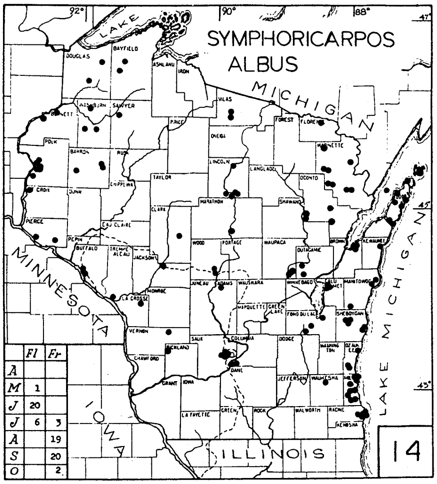
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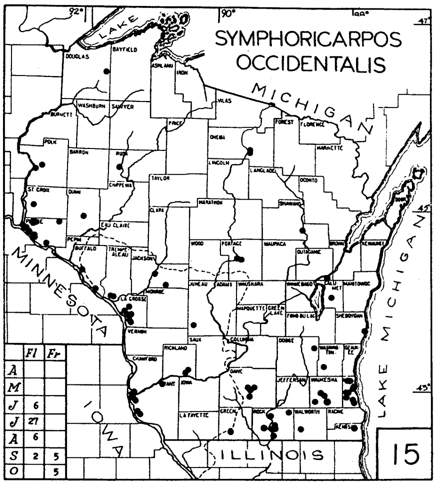
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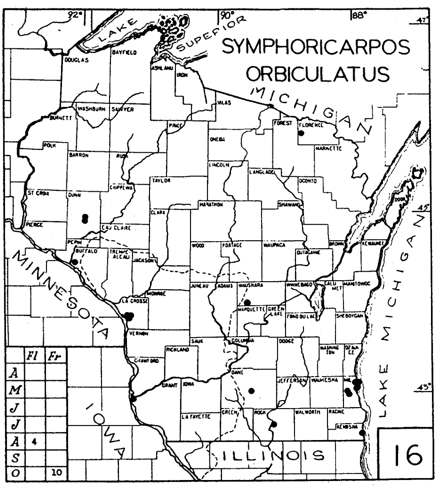
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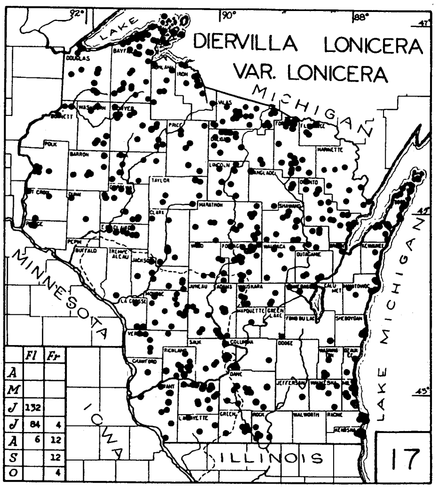
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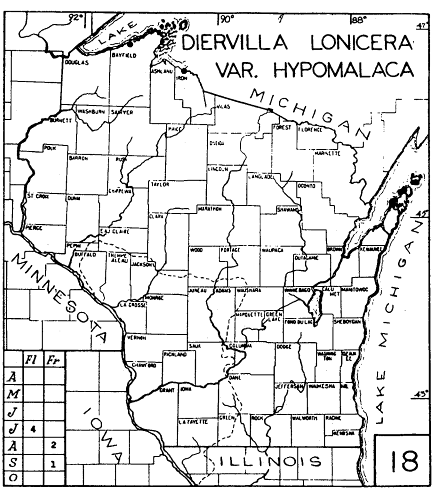
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3. TRIOSTEUM L. Horse Gentian; Feverwort; Wild Coffee

Perennial herbs with erect, coarse, simple and more or less pubescent stems. Leaves opposite, entire, sessile, exstipulate, usually hairy, the blades obovate, oblanceolate to panduriform, tapering to the bases or connate about the stem. Flowers perfect, irregular, sessile, solitary or *in clusters of 2-4 in the axils of leaves,* subtended by bracts or bracteoles. Calyx of 5 linear-lanceolate, foliaceous lobes, persistent Corolla 5-lobed, slightly longer than the calyx, greenish-yellow to dull red, tubular, often hairy within and slightly gibbous at the base. Stamens 5, inserted about the middle of the corolla tube, usually included; filaments short, hairy; anthers linear to oblong, more or less united. Ovary 4-5-locular, but only 3 functional with a solitary ovule in each; style included or slightly exserted, usually hairy below; stigma capitate, 3-5-lobed. Fruit a yellow or red berry, crowned by the persistent calyx, enclosing 3 bony seeds, becoming hard and dry with age.

A genus of 10-12 species, chiefly in eastern Asia and eastern North America. Although included in the tribe Viburneae (Ferguson, 1966), other authors have placed this genus in the Caprifolieae (Lonicereae) or consider it between Viburneae and Linnaeeae. The taxonomic treatment of Lane (1955) is used for the Wisconsin taxa.

Key to Species

A. Principal leaves panduriform, with broadly connate-perfoliate bases; stems mostly glandular-pubescent, the abundant hairs chiefly less than 0.5 mm long; style exserted about 2 mm beyond the corolla; fruit yellow-orange. .... 1. T. perfoliatum.

AA. Principal leaves mostly with narrow bases, sometimes narrowly panduriform and slightly connate at the bases; stems with both glandular and glandless hairs or chiefly with long glandless hairs, over 0.5 mm long; style equalling the corolla or included; fruit bright orange, red or reddish-purple.

B. Stems with glandless hairs, 0.5-1.5 mm long, overtopping shorter glandular hairs; fruit bright orange. .... 2. T. aurantiacum.

BB. Stems with glandless hairs up to 3.0 mm long; fruit red or reddish-purple. .... 3. T. illinoense.

1. Triosteum perfoliatum L.
Tinker's Weed Map 10.

Triosteum perfoliatum L. var. *perfoliatum*

Coarse plant, 0.2-1.0 m tall, with a simple, *densely glandular-puberulent stem. The principal (middle) leaves strongly panduriform,* 1-3 dm long and 3-9 cm wide *with connate enlarged bases* 3-9 cm wide, the upper ones obovate to oblong-ovate, with attenuate bases, velutinous beneath, or glabrous to sparsely pubescent in f. *glaucescens* Weigand. Flowers erect, 3-4 in each leaf axil; calyx lobes 0.9-2 mm wide, with acute or attenuate tips; corolla tubular, slightly bilabiate, yellowish-green to dull purple, densely glandular, the mouth 5-6 mm wide; stamens about equalling the corolla; style usually exserted about 1.5-3.0 mm. Fruit yellow-orange, densely puberulent. 2N = 18.

Locally common in brushy fields, thickets and open woods, often in gravelly or rocky areas, less frequent in open fields or pastured woods, chiefly in the southern one-half of the state. Flowering mid-May to early-July; fruiting early August to October.

2. TRIOSTEUM AURANTIACUM Bicknell
Wild Coffee Map 11.

Triosteum aurantiacum Bicknell var. *aurantiacum*
Triosteum perfoliatum L. var. *aurantiacum* (Bicknell) Weigand

Similar to *T. perfoliatum* but *stems with both glandular and glandless hairs, the latter up to 1.5 mm long. Leaves ovate to oblong-ovate with long tapering bases,* rarely 1-3 pairs slightly panduriform and connate, the lower surfaces densely pubescent. Flowers mostly 1-3 in leaf axils; calyx lobes 1.5-2.8 mm broad, blunt or acute at the tips; corolla red-purple, distinctly bilabiate, the month 7-9 mm wide, exceeding the stamens; style mostly included. Fruit ellipsoid, bright orange-red. 2N = 18.

Plants with glabrous lower leaf surfaces have been designated f. *glaucescens* (Weigand) Lane, and plants with leaves in whorls of 3 have been observed, but no special taxonomic treatment has been described. Scattered throughout the state in rich moist soils along wooded river banks, in moist upland deciduous woods and, occasionally, in conifer-deciduous woods, dry open deciduous woods and in thickets. Flowering mid-May to late-June; fruiting August to October.

3. TRIOSTEUM ILLINOENSE (Weigand) Rydberg Horse Gentian Map 12.

Triosteum perfoliatum L. var. *illinoense* Weig.
Triosteum aurantiacum Bicknell var. *illinoense* (Weig.) Palmer & Steyermark.

Differing from *T. perfoliatum* and *T. aurantiacum* in the *stems having glandless hairs, 1.5-2.5 mm long,* and few or no glandular hairs; *upper leaf surfaces hispid-strigose with hairs up to 1 mm long; calyx ciliate,* with hairs exceeding 1.5 mm in length. Fruits red to reddish purple. Plants with glabrous lower leaf-surfaces have been designated f. *glabrescens* Lane. 2N = 18.

In open oak woods, lightly wooded rocky hillsides, open bluffs and infrequently on slopes above streams in southwestern Wisconsin, extending north to Vernon and Pierce Counties. The distribution pattern and preferences for drier habitats of this species suggests a phytogeographic history which may be associated with the extension of the prairie peninsula during post-glacial time (Iltis, 1963).

TRIBE LINNAEAE FRITSCH

4. LINNAEA Gronovius Twinflower

Trailing or creeping shrub with thin, slightly ligneus, stoloniferous stem and numerous short, erect leafy stems, 3-10 cm high. Leaves *evergreen,* broadly elliptical to suborbicular, 0.5-2 cm broad, slightly crenate above the middle, sparingly ciliate, with obtuse to acute tips and abruptly contracted at the bases into short petioles. *Flowers perfect, borne in pairs (infrequently 3-6) on erect, glandular-setulose peduncles 2-10 cm high.* Calyx of 5 subulate teeth, glandular pubescent. Corolla regular, funnelform to campanulate, 5-lobed, constricted at the base, white and tinged with rose-purple, pubescent within. Stamens 4, in pairs, included within and attached near the base of the corolla tube. Ovary 3-locular, with two abortive and one functional ovule, enclosed by the glandular-pubescent hypanthium; style slender, exserted; stigma capitate. Fruit a 1-seeded capsule (achene), up to 3 mm in diameter, topped by the persistent calyx. 2N = 32.

Named by Jan Fredrik Gronovius to honor the eminent taxonomist, Carolus Linnaeus (1707-1778), who was particularly fond of this plant, one of his portraits shows him holding it.

A circumboreal, and possibly monotypic genus (a morphologically similar taxon has been noted in China which may be a distinct species) with the species, *L. borealis* L., subdivided into Eurasian and American subspecies or varieties. The corolla of the Eurasian plants is companulate, mostly less than 10 mm in length with the tube flaring from within the calyx and the leaves are mostly orbicular to ovate, rarely elliptic. In contrast, our plants have a funnel-form corolla, often 10 mm or more long, with the tube flaring at or above the tip of the calyx teeth and the leaves are usually elliptic to obovate and less commonly orbicular. Gleason and Cronquist (1963) consider all American plants as *L. borealis* var. *longifolia* Torr., while Fernald (1950) and Hulten (1970) separate them into two varieties or subspecies. Hulten's treatment seems valid in considering the west coast plants, with longer corollas and more acute-tipped leaves, as distinct subspecies from the wide-ranging eastern and northern plants with shorter corollas and obtuse to nearly round-tipped leaves. Fernald (1950) also distinguishes between these two races, but designates them as varieties. It is also possible to consider the American entities as a distinct subspecies which contain two geographic races which may be designated as varieties. This latter treatment is used in this report to maintain the taxonomic treatment which has long been used.

The Wisconsin plants are designated:

1. LINNAEA BOREALIS L. var. AMERICANA (Forbes) Rehd. American Twinflower Map 13.

Linnaea borealis L. subsp. *americana* (Forbes) Rehd.
Linnaea borealis L. var. *longiflora* Torr.
Linnaea americana Forbes

Locally abundant in the northern one-third of Wisconsin (often with *Cornus canadensis, Trientalis borealis, Coptis trifolia, Clintonia borealis* and *Lycopodium* spp.) on hummocks and on decaying stumps and logs in sphagnum bogs, hemlock-hardwood forests, maple woods and pine forests, less common on sandy soils in pine woods. In southeastern Wisconsin it occasionally occurs in bogs or in wooded ravines along the Lake Michigan shore, while in central and southern parts of the state it persists in boreal relicts and sandstone rock outcrops. Flowering late-May to July; however, no mature fruits were observed on any Wisconsin specimens nor on any specimens from elsewhere in northeastern North America. Fernald (1950) and Gleason and Cronquist (1963) also mention little or nothing about the fruits. Polunin (1959) indicates the fruit size is about 3 mm long and remarks, "they are rarely developed." This species ranges throughout the boreal zone of the northern hemisphere, including the western cordilleran region of North America. The question arises as to how such a widespread migration could have occurred with such limited seed production. Apparently the climatic conditions favorable for seed production presumably present during the time of post-glacial migration no longer prevail, or occur sporadically, and the species is perpetuated where it presently occurs chiefly by vegetative propagation.

5. SYMPHORICARPOS DUHAMEL
SNOWBERRY

Branching low, upright or arching shrubs, 0.3 to 2 m tall, sometimes sprouting from the roots and with *flowers or fruits sessile or on short pedicels in terminal or axillary racemes or spikes.* Winter buds with 2 pairs of scales. Leaves are ovate-oblong, oval to rotund, exstipulate, short petioled, entire to coarsely crenate or shallowly lobed with acute to rounded tips and bases. Flowers perfect, subtended by small bracts or bracteoles. Calyx 4-5 toothed, persistent. Corolla 4-5-lobed, white to purplish, regular or slightly irregular, campanulate to tubular-funnelform or salverform, sometimes slightly gibbous at the base and often villous within. Stamens 4-5, equal, inserted near the top of the corolla tube, included or exserted; filaments short, sometimes villous; anthers oblong or linear. *Ovary 4-locular, with 2 fertile 1-ovuled locules;* style glabrous or hairy, shorter than the corolla; stigma capitate or slightly lobed. Fruit a white or red globular or ellipsoid berry (drupe) containing 2 oblong stony seeds, with small embryos and copious endosperm.

A genus of 15-16 species in North America and one in central China.

Key to Species and Varieties

A. Corolla 5-9 mm long; fruit white; twigs with hollow pith.

B. Corolla 5-6 mm long; style and stamens shorter than or equalling the corolla, not exserted; style 2-3 mm long, glabrous.

C. Low shrub, less than 1 m tall; young twigs pubescent with short incurved hairs; leaves glaucous and pilose beneath. . . . . 1a. SYMPHORICARPOS ALBUS var. ALBUS.

CC. Erect or arching shrub, 1-3 m tall; young twigs glabrous; leaves glabrous to sparsely pilose beneath. . . . . 1b. SYMPHORICARPOS ALBUS var. LAEVIGATUS.

BB. Corolla 6-9 mm long; style and stamens exserted; style 4-8 mm long, pilose near the middle, rarely glabrous. . . . . 2. SYMPHORICARPOS OCCIDENTALIS.

AA. Corolla 3-5 mm long; fruit red or coral; twigs with solid pith. . . . . 3. SYMPHORICARPOS ORBICULATUS.

1a. SYMPHORICARPOS ALBUS (L.) Blake var. ALBUS Snowberry Map 14.

Low, bushy shrub, 0.2 to 0.8 m tall, with slender, *minutely pubescent branchlets* and *winter buds with ciliate or pubescent scales.* Leaves elliptic-ovate to suborbicular, 1-5 cm long and 1-4 cm broad, on petioles 2-5 mm long, the margins ciliate, entire to undulate or rarely lobed on the young branches, tips acute to apiculate and bases acute to nearly rounded, *lower surfaces glaucous and pilose at least on the veins* or frequently densely pilose throughout, upper surfaces green, sparsely puberulent to glabrous. Flowers on short pedicels, 1-5 in terminal clusters or in the axils of the upper leaves. Calyx 5-toothed, glabrous or slightly ciliate. Corolla white or pink, campanulate, somewhat gibbous at the base, mostly 5-6 mm long, *the lobes 2-3 mm long, shorter than the tube,* bearded within. *Stamens shorter than the corolla;* anthers 1-1.5 mm long. Style 2-3 mm long, shorter than the corolla; stigma capitate. Fruit a white berry, 6-10 mm in diameter, with 2-stony seeds, pendent from the underside of the branchlet. 2N = ca.54.

Chiefly a northern species, extending southward to Richland, Sauk and Racine Counties where it is locally abundant at the margins of open northern hardwood forests, in jack pine woods, on wooded ravine slopes and on stabilized, lightly wooded sand dunes, less common on gravelly, rocky and sandy slopes, sandstone and limestone rock outcrops, dry wooded slopes, sandy oak woods and in second growth forest stands. Flowering late-May to July; fruiting late July to October.

1b. SYMPHORICARPOS ALBUS (L.) Blake var. LAEVIGATUS Blake
Western Snowberry

An erect, branching shrub, 1-3 m tall, with slender, *usually glabrous branchlets* and *winter buds with glabrous scales.* Leaves oval to nearly orbicular, 2-3 cm long and 7-15 mm wide, on petioles 2-4 mm long, tips acute to obtuse and bases acute, the upper surfaces green and glabrous, *the lower slightly paler, glabrous or slightly* *pubescent,* margins entire to sinuate or lobed on young shoots, glabrous or sparsely ciliate. Flowers numerous in short peduncled racemes 1-2.5 cm long at the tips of the branches and sometimes in the axils of the upper leaves. Floral features similar to var. *albus* except *corolla lobes longer than the tube.* Fruit white, subglobose or ellipsoid, the larger ones 12-15 mm in diameter, pendent in clusters. 2N = 54.

A western species, ranging from southeastern Alaska to California and eastern Montana; frequently planted as an ornamental in parks and home yards, escaping to adjoining open woods, thickets and along railroad embankments. Only a few noncultivated specimens were observed in the various herbaria; therefore, this variety is not mapped. Flowering and fruiting dates are similar to those of var. *albus.*

2. SYMPHORICARPOS OCCIDENTALIS Hooker
Wolfberry Map 15.

Densely clumped shrub, 0.3 to 1 m tall, *sprouting from rhizomes* and with *reddish-brown, puberulent branchlets.* Leaves oval, 2.5-11 cm long and 1.5-7 cm wide, *thick and firm when mature, entire or often with undulate, coarsely crenate or lobed margins,* with obtuse and apiculate tips, cuneate to rounded bases and petioles 4-10 mm long, upper surfaces dull, dark green, glabrous to sparsely pilose, lower surfaces pale green, thinly pubescent at least along the veins, rarely glabrous. Flowers sessile, in terminal spicate clusters 1-2.5 cm long and in dense axillary clusters. Calyx 5-toothed, the teeth ovate, ciliate, 0.7-0.8 mm long. Corolla campanulate, pinkish, 6-9 mm long, *the lobes 3-4 mm long, longer than the tube.* Stamens 5, *exserted.* Style 4-8 mm long, exserted, longer than the stamens, pilose near the middle; stigma capitate, yellow. Fruit globose, pale greenish-white, 6-8 mm in diameter. Chromosome number not determined.

Locally abundant, in the southern one-half of the state, in prairies, on railroad embankments, dry hillsides and bluff tops, along borders of upland woods and sandy roadsides, occasionally in pastures, extending northward and northwestward in sandy barrens and along railroad embankments. Flowering mid-June to early-September; fruiting September to October.

3. SYMPHORICARPOS ORBICULATUS Moench
Coralberry Map 16.

Leafy, erect shrub 0.5 to 2 m tall, with *light brown to purplish branches* and densely puberulent twigs. Leaves oval, ovate to nearly orbicular, 1-4 cm long, on petioles 2-4 mm long, the blades with entire to undulate margins, acute to obtuse tips, rounded to acutish bases, dull green and glabrous or sparsely pilose on the upper surfaces and paler, glaucous to soft pubescent beneath. Flowers densely crowded or on short spikes in the axils of several to many of the upper leaves. Calyx 5, tooth-like, *persistent in fruit to form a beak about 1 mm long.* Corolla, *3-5 mm long,* pink, broadly campanulate, villous within, the lobes about as long as the tube. Stamens 5; anthers about 1 mm long, shorter than the filaments. Style 2 mm long, pilose. Fruit elliptical, 5-7 mm long and 4-5 mm broad, glabrous, *coral-red, pink or sometimes purplish.* 2N = 18.

Infrequent at margins of woods, along railroad embankments, on dry open or lightly wooded hillsides and along riverbanks in southern Wisconsin, elsewhere escaping from yard plantings or parks to roadsides and open woods. Flowering July to September; fruiting September to October.

Kolkwitzia amabilis Graebn., the beauty bush, a tall shrub with peeling bark, *bristly-hairy pedicels and hypanthia* and rose-colored, tubular to campanulate flowers is often planted as an ornamental in home yards, city and county parks and in horticultural gardens. Its hardiness especially in southern Wisconsin indicates it may eventually escape to adjacent roadsides, fencerows and open woods.

TRIBE DIERVILLEAE C. A. MEYER

6. DIERVILLA MILLER

BUSH HONEYSUCKLE

Stoloniferous, upright or slightly arching shrubs, up to 1.5 m tall. Winter buds with several pairs of pointed scales. Leaves ovate, ovate-lanceolate to oblong-ovate, 6-12 cm long and 2-7 cm broad, *with acuminate tips* and acute to nearly rounded bases, finely serrate, glabrous above and glabrous to densely pubescent beneath, *on short petioles, 5-10 mm long, from which extend two hispid decurrent lines on the stem.* Flowers several on short pedunculate cymes, terminal or axillary in the upper leaves. Calyx lobes 5, linear-lanceolate, extending from the constricted neck of the hypanthium. Corolla, funnelform, yellow, becoming orange or red after anthesis, 5-lobed, more or less bilabiate, with a 4-lobed upper lip and a single lower lip, the tube slightly gibbous at the base and densely hairy within. Stamens 5, inserted near the tip of the tube; filaments pubescent; anthers linear, pubescent, introrse, usually exserted. Ovary elongate, *2-locular with many ovules and parietal placentation;* style long, slender, densely pubescent in lower portion, equal in length or slightly longer than the corolla tube; stigma capitate. *Fruit an elongated, thin-walled, septicidal capsule, beaked with the persistent calyx.* Seeds small, ovoid, with large cotyledons and fleshy endosperm.

A genus of 2 (or 3) species in eastern North America and about 12 species in eastern Asia, sometimes combined with the genus *Weigela* Thun., which is characterized by larger pink to red flowers, woody capsules and winged seeds. *Weigela florida* (Bunge) A. DC., a shrub 1-3 m tall, with large (3-3.5 cm long and nearly 3 cm broad) and pink to crimson flowers, is widely planted as an ornamental and occasionally is found persisting in abandoned gardens and in open areas adjacent to parks and botanical gardens.

Diervilla lonicera Mill. is the only native species in Wisconsin and is represented by two varieties:

1a. DIERVILLA LONICERA Miller var. LONICERA Map 17.

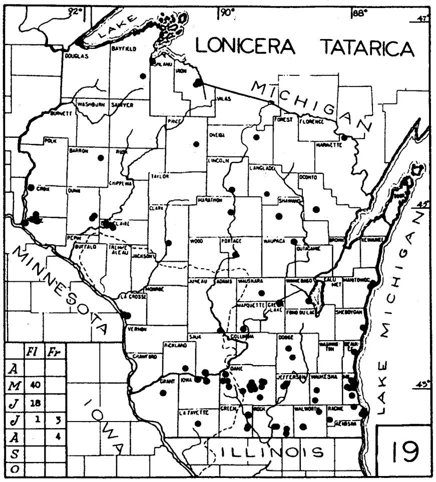
Shrub up to 1.5 m tall, with glabrous twigs, except for 2-hispid decurrent lines extending from the petiole of each leaf and with ovate, ovate-lanceolate to oblong-ovate leaves, on petioles 5-10 mm long, the tips acute to acuminate and bases acute to rounded, margins finely serrate, more or less ciliate; upper surfaces glabrous; *lower surfaces glabrous to more or less pubescent on the veins.* Flowers 10-12 mm long; corollas funnelform, yellowish, turning orange to red after anthesis. Fruit 10-15 mm long, constricted near the tip and beaked with the persistent calyx lobes. $2N = 18$.

Widespread throughout the state, often locally common in large clones at the margins of dry to mesic upland hardwood forests, northern hardwood forests, pine woods, cut-over areas, open or lightly wooded rocky slopes, less abundant in pastured woods, on dry hillsides, along railroad embankments and roadsides. Flowering June to mid-August; fruiting late-July to October.

1b. DIERVILLA LONICERA Miller var. HYPOMALACA Fernald Map 18.

Similar to var. *lonicera* but *leaves densely pilose beneath.*

Chiefly in Door County and along the Lake Superior shore in Iron and Bayfield Counties where it occurs with var. *lonicera* in open northern hardwoods stands, on sandy beaches above the high water mark and in aspen stands. It is also present in northeastern Minnesota, upper Michigan and along the northern shore of Lake Huron. The greatest concentration of these densely pubescent plants, according to Fassett (1942), is in the area north of Lake Huron. Flowering and fruiting dates are similar to those of var. *lonicera.*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ILLINOIS
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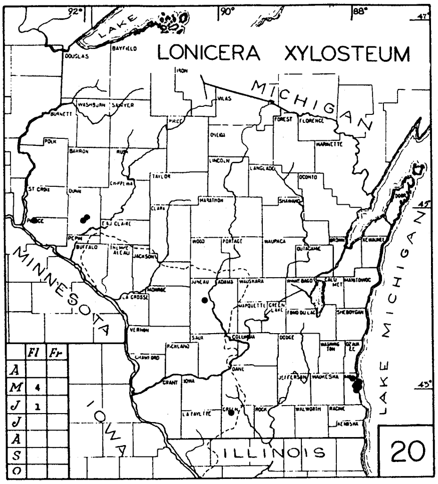
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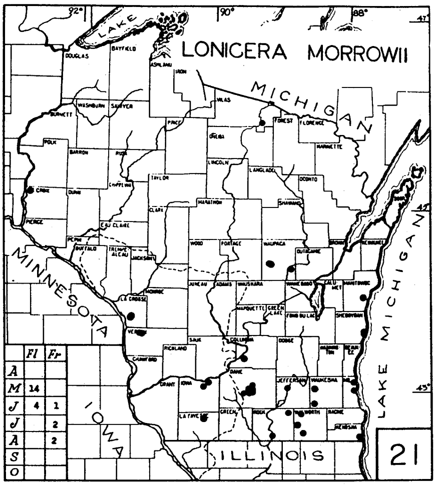
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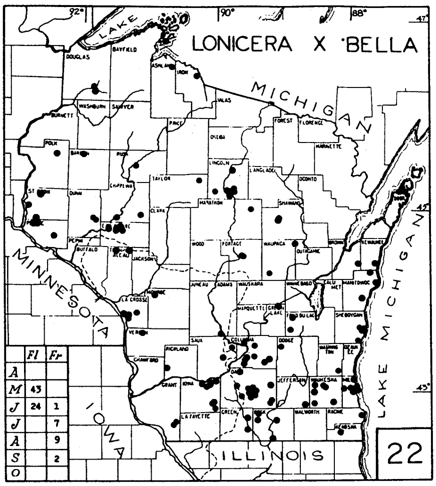
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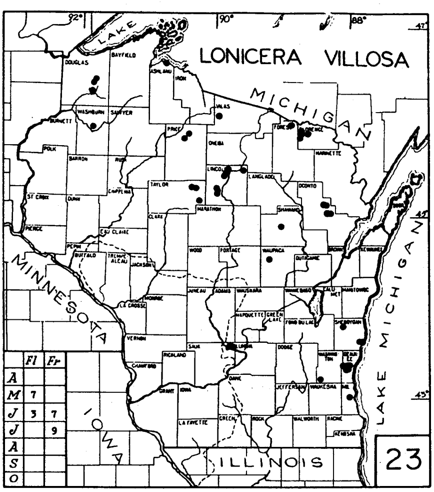
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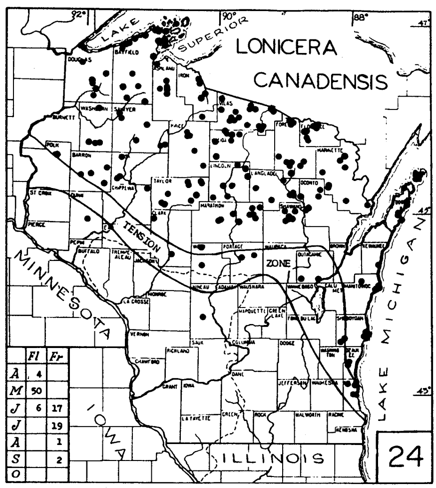
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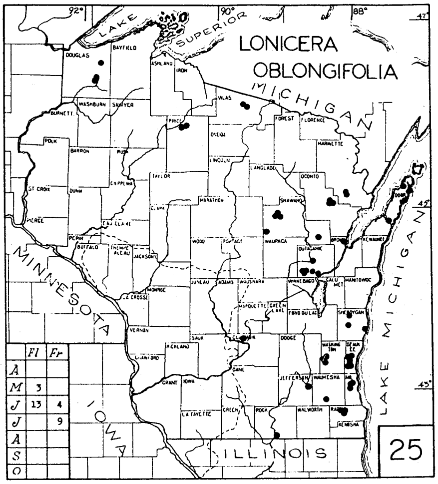
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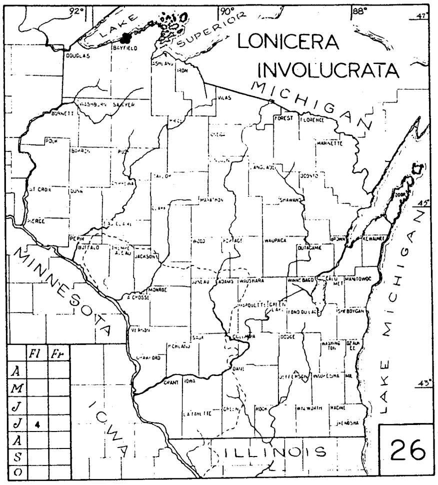
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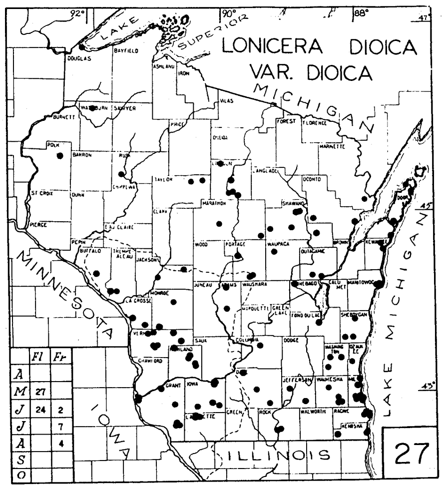
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VAR. DIOICA
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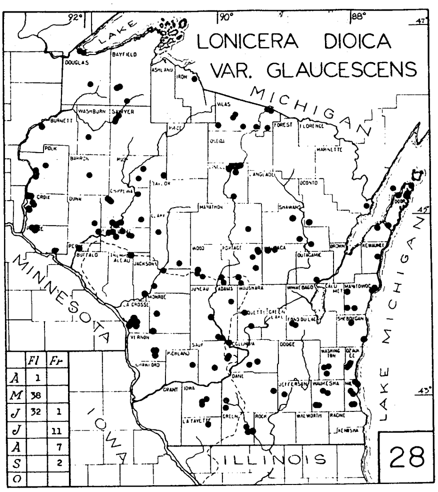
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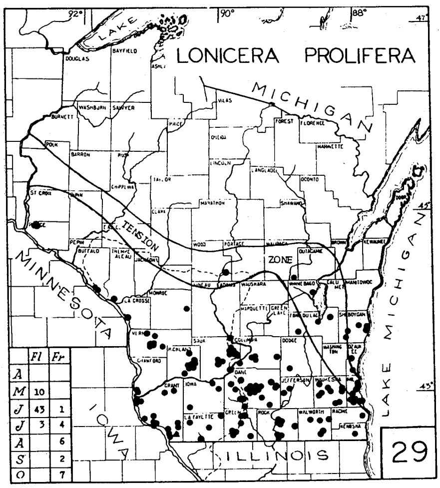
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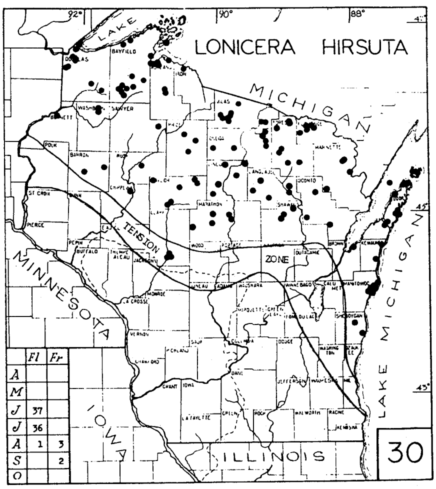
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LAKE MICHIGAN
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A
M
J 37
J 36
A 1 3
S 2
O
30

TRIBE LONICERAEAE R. BROWN EX. DC.

7. LONICERA L. HONEYSUCKLE

Climbing or erect, deciduous shrubs. Winter buds with 2-several outer scales. *Leaves entire* (slightly lobed or toothed in one introduced species), *exstipulate, short-petioled, sessile or connate,* the surfaces glabrous or hairy. Inflorescences of 2-3-flowered axillary cymes, or in axillary or in terminal clusters. Flowers regular or irregular, perfect, subtended by *2-4 paired bracteoles.* Calyx 5-toothed, short. Corolla tubular or funnelform, sometimes gibbous, 5-lobed, regular or bilabiate with a 4-lobed upper lip and a 1-lobed lower lip. Stamens 5, attached near the top of the corolla tube; filaments long and slender; anthers oblong to linear, introrse, usually exserted. *Ovary mostly 2-3 locular with 3-8 ovules* and axillary placentation; style slender, equalling or slightly longer than the corolla tube; stigma capitate. Fruit a several-seeded berry. Seeds ovoid, with a smooth or reticulate seed coats and fleshy endosperms.

A genus of about 180 species in temperate regions of the northern hemisphere with several species extending to tropical regions at higher elevations. About 25 species occur in North America; seven are native to Wisconsin and five are introduced and have become established. A number of other introduced species are planted in horticultural gardens. The species are classified into two subgenera: *Lonicera* (*Chamaecerasus* L.), characterized by axillary inflorescences with the flowers in pairs and the leaves distinct, and *Caprifolium* (Mill.) Pers. (*Periclymenum* L.), with the flowers in terminal cymes and the upper leaves usually connate (Ferguson, 1966). These subgenera are sometimes further divided into sections based on the regular or irregular corolla, length of corolla tube, erect or climbing habit and whether the bracteoles are free or connate (Rehder, 1903).

KEY TO SPECIES

A. Leaves all distinct; flowers or fruits in pairs on single axillary peduncles.
  B. Erect or ascending shrubs; corollas 1-2 cm long.
    C. Bracts below the flowers scale-like or linear, less than .5 cm long.
      D. Pith of twigs hollow.
        E. Leaves and twigs glabrous. . . . . 1. L. TATARICA.
        EE. Leaves and twigs more or less pubescent.
          F. Flowers pale yellow; filaments pubescent; leaves elliptic-ovate to obovate. . . . . . 2. L. XYLOSTEUM.
          FF. Flowers pink or white, fading to yellow; filaments glabrous; leaves ovate to oblong.
            G. Leaves pubescent beneath; peduncles, twigs and calyx densely hairy; bractlets between ¾ and the full length of the ovary, hairy; flowers white fading to yellow. . . . . 3. L. MORROWII.
            GG. Leaves sparsely pubescent, with a few hairs on the veins beneath; peduncles, twigs and calyx sparsely hairy; bractlets mostly up to ½ the length of the ovary (occasionally up to ⅔ its length), sparsely hairy and sometimes with a few glands flowers pink fading to yellow. . . . . 4. L. X BELLA.
      DD. Pith of twigs solid.

H. Peduncles rarely more than 1 cm long, usually shorter than the flowers; ovaries wholly united; fruit blue. .... 5. L. VILLOSA.

HH. Peduncles mostly 2-4 cm long, longer than the flowers; ovaries separate; fruit red.

I. Lobes of the corolla much shorter than the tube; leaves oblong-ovate, glabrate, the margins and petioles ciliate. .... 6. L. CANADENSIS.

II. Lobes of the corolla nearly as long as the tube; leaves oblong to narrowly obovate, minutely pubescent beneath, not ciliate. .... 7. L. OBLONGIFOLIA.

CC. Bracts below the flowers broadly oval and leaf-like, almost enclosing the flowers, 1-2 cm long. .... 8. L. INVOLUCRATA.

BB. Climbing or trailing vines; corollas 2-4 cm long. ..... 9. L. JAPONICA.

AA. Uppermost leaves connate; flowers or fruits in sessile, terminal or sometimes axillary clusters.

J. Leaves glabrous above, glabrous or minutely pubescent beneath; margins glabrous.

K. Connate upper leaves longer than broad, green above and whitened beneath, pointed or mucronate at the tips. .... 10. L. DIOICA.

KK. Connate upper leaves forming a nearly round disk; glaucous above. .... 11. L. PROLIFERA.

JJ. Leaves pubescent and green on both sides or grayish beneath; margins villous-ciliate. .... 12. L. HIRSUTA.

SUBGENUS LONICERA

(Subgenus *Chamaecerasus* Rehd. not L.)

1. LONICERA TATARICA L.

Tartarian Honeysuckle Map 19.

Upright shrub, 1.5 to 3 m high, the stems with grayish bark, glabrous twigs and brown hollow pith. *Leaves mostly ovate, sometimes oval to oblong,* 3-7 cm long and 1.5-4 cm wide, on petioles about 5 mm long, with acute to obtuse tips and *cordate or rounded bases, glabrous or with a few sparse hairs* beneath. Flowers white to pinkish-purple, in axillary pairs on slender glabrous peduncles, 1.8-2 cm long, subtended by two *glabrous ovate bractlets which are rarely half as long as the ovaries,* and two longer essentially glabrous bracts which are shorter or longer than the ovaries. Calyx of 5, lanceolate sepals. Corolla bilabiate, about 1.5 cm long, glabrous, gibbous at the base and hairy within, the lobes linear to lanceolate, as long or longer than the tube. Stamens slightly exserted, the filaments hairy. Ovaries slightly united at the base, glabrous, the *styles hirsute.* Fruit a red or sometimes yellow berry. 2N = 18.

White-flowered forms have been designated f. *albiflora* (DC.) House.

A species of central Asia which is often planted as an ornamental in home yards, parks and botanical gardens, and is now widely distributed, probably transported by birds, throughout Wisconsin in open woods, pastured woodlots, on gravelly and quarry bluffs, along roadsides, fencerows and railroad embankments and edges of woods, often bordering parks and horticultural gardens. Flowering early-May to late-June; fruiting July to August.

2. LONICERA XYLOSTEUM L.

European Fly Honeysuckle Map 20.

Upright shrub, 1-2.5 m high, with soft-pilose to glabrous twigs and hollow branches. *Leaves elliptic-ovate to obovate, usually* *broadest above the middle,* 3-6 cm long and 1-4 cm broad, acute to slightly acuminate at the tips and rounded to broadly acute to obtuse at the bases, sparingly pilose above and densely pubescent beneath. Flowers axillary, on pubescent, filiform peduncles 0.6-2 cm long, *subtended by two elliptic or oval, pubescent and glandular bractlets* which are about one-half to two-thirds as long as the ovary and two linear, pubescent-glandular bracts which equal or exceed the ovaries. Calyx 5-lobed, pubescent-glandular. Corolla bilabiate, *yellowish-white* to sometimes slightly pinkish, 7-12 mm long, pubescent. Stamens 5; *filaments pubescent.* Ovaries densely pubescent with simple and glandular hairs. Fruits are deep red berries. 2N = 18.

An Eurasian species which is sometimes planted as an ornamental and occasionally escapes into waste areas, into open woods bordering parks and horticultural gardens, and sometimes persists on abandoned homesteads. Flowering May to June; fruiting July to August.

3. Lonicera morrowii Gray
Morrow's Honeysuckle Map 21.

Upright shrub, up to 2 m tall, with grayish-brown bark, spreading branches and finely pubescent twigs. *Leaves oblong to narrowly elliptic,* 2.5-5 cm long and 1.5-2.5 cm wide, on short petioles, with obtuse to nearly rounded tips and cordate to rounded bases, the upper surfaces finely and sparsely pubescent, the *lower surfaces grayish-tomentose.* Flowers in pairs, on densely pubescent axillary peduncles 0.5-1.5 cm long, subtended by two ciliate-tipped *bractlets which are three-fourths of or equal in length to the ovaries,* and by two densely pubescent bracts which exceed the ovaries. Calyx 5-toothed, *ciliate. Corolla white, fading to yellow,* pubescent externally, about 1.5 cm long, the 5-lobes only slightly irregular. Stamens exserted; *filaments glabrous.* Ovaries separate, glabrous. Fruit a red or yellow berry. 2N = 18.

A native of Japan which is sometimes planted as a border shrub in home yards, parks and in horticultural gardens, occasionally escaping to nearby roadsides, abandoned fields and infrequently persisting about abandoned dwellings. Flowering early-May to mid-June; fruiting late-June to late-August.

4. Lonicera X bella Zabel
Bell's Honeysuckle Map 22.

Similar to *L. tatarica* but the *twigs are sparsely pubescent and the leaves are somewhat pubescent beneath, at least on the veins.* Flowers pink to purple-red fading to yellow, 1.5-1.8 cm long, on sparsely pilose peduncles 10-12 mm long, subtended by more or less *ciliate bractlets which are mostly one-half, but sometimes two-thirds, the length of the ovary* and by sparsely pubescent bracts which exceed the ovary in length.

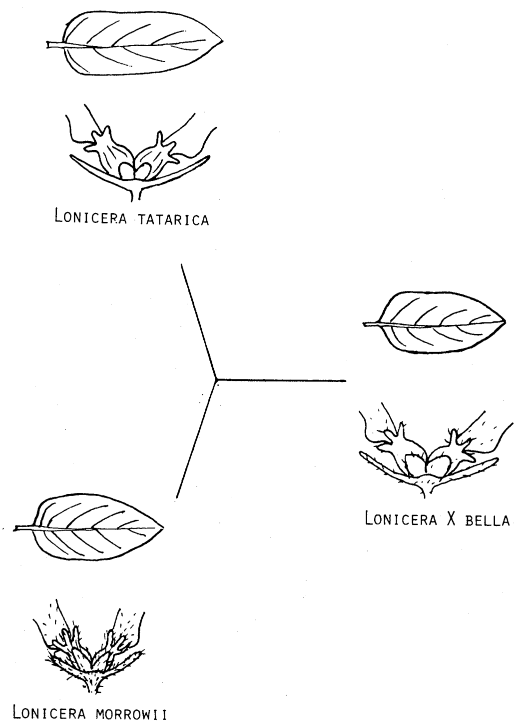

Fig. 1. Sketches of ovaries, bractlets, bracts and leaf outlines of *Lonicera tatarica, L. morrowii* and their hybrid, *L.* X *bella* (adapted from Green (1966)

This honeysuckle is a fertile hybrid between *L. tatarica* and *L. morrowii* (Fig. 1) which has been reported to arise spontaneously in cultivation from naturalized plants of the parental species (Green, 1966, Hauser, 1966; Barnes and Cottam, 1974). Backcrosses with both parents apparently occur as a number of specimens show wide variations in the degree of pubescence of the leaves, bractlets and bracts which sometimes make it impossible to clearly identify individuals. 2N = 18.

This hybrid plant appears to be more adaptable than its parents growing in woodland borders, fallow fields, pastured woodlots, second growth woods of oak, ash and basswood, on open slopes and sometimes along lake and stream banks and river bottoms. Flowering early-May to late-June; fruiting July to September.

Lonicera maackii Maxim, an introduction from Asia, has been sighted as an escape in several southern counties. This upright shrub is distinguished by the elliptic, oblanceolate to obovate leaves with acuminate tips and long-tapering bases and the flowers and fruits borne in pairs on bractless peduncles which are shorter than the petioles. Hauser (1965) reported this species is reproducing and spreading in Ohio's strip mining areas, and it may be only a question of time before it is established in Wisconsin.

5. Lonicera villosa (Michx.) R. & S.
Mountain Fly Honeysuckle Map 23.

Low, diffuse or erect shrub, up to 1 m tall, *with strongly ascending branches,* shreddy bark, and *reddish brown, more or less pilose-villous twigs.* Winter buds scaly, appressed or ascending, usually without accessory buds. *Leaves narrowly oblong to oblong-lanceolate or elliptic,* 2.4 cm long and 0.8-1.6 cm wide, sessile or on short petioles, the tips rounded or obtuse and generally mucronate, the bases rounded or obtuse, margins ciliate, upper surfaces glabrous to slightly strigose, the *lower surfaces with prominent veins and more or less villous.* Flowers paired on axillary peduncles (3-10 mm long), *their ovaries completely united* and appearing as one, *the subtending bractlets enclosing the ovaries* and the bracts 3-5 mm long, longer than the ovaries. Calyx of 5 teeth-like lobes. *Corolla pale yellow, narrowly campanulate,* 10-15 mm long, the tube slightly gibbous at the base and slightly longer than the nearly equal 5 lobes, glabrous or sparsely pubescent externally and villous within. Stamens 5, exserted. United ovaries glabrous or sparsely pubescent; styles glabrous. Fruit a bluish berry, bearing the scars of the two flowers at the summit. No chromosome numbers have been recorded.

Gleason and Cronquist (1963) consider this species as variable in pubescence and suggest it may be better considered as a variety of the Eurasian *L. caerulea* L. Fernald (1950) describes it as a polymorphic American species and divides it into five varieties. If Fernald's treatment is followed, the Wisconsin plants are designated *L. villosa* var. *solonis* (Eat.) Fern.

This boreal shrub is occasionally present in moist, acidic soils of open *Chamaedaphne-Sphagnum* bogs, *Picea-Larix* bogs and sometimes in alkaline to acidic *Carex-Eriophorum* meadows in northern Wisconsin; it is infrequent to rare in bogs of southeastern Wisconsin and is apparently absent in the Driftless Area. Flowering early-May to late-June; fruiting mid-June through July.

6. Lonicera canadensis Marsh.
Fly Honeysuckle Map 24.

Straggly-branched shrub, up to 1.5 m high, with grayish bark, glabrous twigs and scaly winter buds. *Leaves ovate to oblong-ovate,* 3-10 cm long and 2-4 cm wide, on short, distinct, *ciliate petioles,* acute to obtuse at the tips, with *cuneate, rounded or rarely cordate bases,* glabrous or sparsely pubescent beneath and the *margins ciliate.* Flowers axillary in pairs, on peduncles 2-3 cm long, subtended by *minute bractlets* (or none) and orbicular to elliptic bracts which are shorter than to slightly longer than the ovaries. Calyx of 5 lobes, about 1 mm long. Corolla greenish-yellow, *nearly regular,* 1.2-2 cm long, gibbous at the base, funnelform, expanding into nearly equal 5 lobes which are *shorter than the tube,* slightly hairy within. Stamens glabrous, mostly included. Ovaries of the paired flowers distinct and divergent in fruit, glabrous; style glabrous. Fruit a reddish, elongated berry. 2N = 18.

General range in Wisconsin is north of the Tension Zone where it is locally common in northern hardwood forests, maple-beech woods, pine-maple woods and less commonly in second-growth maple-birch woods and in boggy woods; it also occurs infrequently in rocky maple-oak woods of the central counties and in maple-beech-basswood stands in ravines, on bluff tops and on morainic ridges in the southeastern counties. Flowering late-April to mid-June; fruiting mid-June to September.

7. LONICERA OBLONGIFOLIA (Goldie) Hook. Swamp Fly Honeysuckle Map 25.

Shrub up to 1.5 m high, with grayish bark, ascending, minutely pubescent branches and scaly winter buds. Leaves oblanceolate to oblong, 3-10 cm long and 1-3 cm wide, the tips acute to obtuse and the *bases tapering to short petioles* (mostly less than 2 mm) or sessile, the margins not ciliate, upper surfaces glabrous or sparsely puberulent and the lower surfaces puberulent. Flowers in the axils of leaves, in pairs on *peduncles 1-3 cm long,* the *subtending bracts much shorter than the ovaries* or early deciduous. Calyx of 5 minute teeth, less than 0.5 mm long. Corolla pale yellow, 10-15 mm long, *deeply bilabiate,* gibbous near the base, the upper lip 4-lobed and the lower 1-lobed, more or less pubescent within and without. Stamens 5, with hairy filaments. Ovaries of the two flowers slightly united at their bases; styles hirsute. Fruits are reddish or purplish berries, more or less united in pairs. Chromosome numbers have not been determined.

A native shrub of the coniferous forest region, occurring in bogs, sedge meadows, boggy lake shores and moist willow thickets, chiefly in the glaciated northern and eastern portions of the state. The sparsity of dots on the map is probably the result of limited collecting because of its affinity for moist mucky habitats. Flowering mid-May to mid-June; fruiting late-June through July.

8. LONICERA INVOLUCRATA (Richards) Banks Fly Honeysuckle Map 26.

Upright to sometimes straggling shrub, 1-3 m tall, often spreading by root sprouts, with stout branches and glabrous 4-angled twigs. *Leaves ovate, obovate to elliptic-oblong, 6-12 cm long and 2-5 cm broad,* short acuminate at the tips, tapering at the bases to short petioles, green and glabrous above, paler and hirsute on the veins beneath. Flowers in axillary pairs, on peduncles 2-4 cm long, subtended by *4 greenish to dark purple, ascending to reflexed, foliaceous bracts 1-2 cm long.* Calyx minute or obsolete. Corolla yellow, 10-13 mm long, tubular to funnelform and saccate at the base, nearly regular, the short, slightly subequal lobes erect, mostly less than half as long as the tube. Stamens glabrous, shorter or about as long as the corolla. Ovaries 3-celled, distinct; style exserted and glabrous. Berries purple-black, subtended by the persisted bracts. Chromosome numbers have not been determined.

A boreal-cordilleran species which occurs in cool, moist, shaded sites in the northern Great Lakes region. It has been collected at only one locality in Wisconsin: Bayfield County, Lake Superior region near Port Wing (*L. S. Cheney, 7055, July 9, 1897, WIS, UWM; 7169, July 10, 1897, WIS; 7173, July 11, 1897 WIS*). Flowering June to July; fruiting in August.

9. LONICERA JAPONICA Thumb. Japanese Honeysuckle

Climbing or trailing vine with pubescent young twigs and branches. Leaves ovate to oblong, 4-8 cm long and 2-4 cm wide, entire or *sometimes slightly toothed or lobed,* short petioled, with obtuse to acute tips and rounded or broadly cuneate bases and both surfaces slightly pubescent to nearly glabrous. Flowers in axillary pairs, on peduncles 5-10 mm long, subtended by ovate, *foliaceous bracts which are longer than the ovary and by rotund, ciliate bractlets that are shorter than or nearly equal in length of the ovary. Calyx long-toothed.* Corolla bilabiate, 3-5 cm long, white or cream-colored, sometimes tinged with purple, becoming yellow with age, very fragrant, the pubescent tube about equalling the limb. Stamens exserted. Ovary pubescent. Fruit a black berry. 2N = 18.

A species of eastern Asia which has become a noxious weed in southern and southeastern United States where it overwhelms shrubs and small trees. It has been planted in several places in southern Wisconsin as an ornamental and to stabilize steep slopes. Recently it has been reported as an escape along the bank of the Milwaukee River in Milwaukee County. Except for the Milwaukee specimens there is no other evidence of the extent of naturalization or hardiness of this species in the state. Flowering May to June; fruiting September to October.

SUBGENUS CAPRIFOLIUM (MILL.) PERS. (Subgenus *Periclymenum* Rehd. not L.)

10. LONICERA DIOICA L. Wild Honeysuckle

Twining, trailing or loosely ascending shrub with glabrous and glaucous twigs and the older stems with grayish, peeling bark. *Leaves oblong, elliptic or obovate,* 4-10 cm long and 1.5-4 cm wide, rounded, obtuse to sometimes acute at the tips and tapering at the bases or sometimes with short petioles, *green above and whitened beneath,* the upper 1-4 pairs connate-perfoliate, *the uppermost pair forming an elliptic-ovate to rhombic involucral disk.* Flowers terminal, in 1-3 whorls on short peduncles. Calyx obscurely 5-lobed, glabrous. Corolla bilabiate, 1.5-2.5 cm long, pale yellow to reddish or purplish, glabrous to pubescent externally and hairy within, the tube gibbous on one side at the base and gradually expanding upward, about equal in length to the lobes. Stamens exserted, the slender filaments hairy. Ovary glabrous; the style more or less hairy. Fruit a red berry. 2N = 18.

Gleason and Cronquist (1962) and Fernald (1950) recognize several varieties and forms of this species. The following are present in Wisconsin:

10a. LONICERA DIOICA L. var. DIOICA Map. 27.

Leaves glabrous and glaucous beneath, the corolla glabrous externally and hairy within and the *style glabrous to sparsely hairy.* Plants with upper leaves in whorls of three have been designated f. *trifolia* Vict. & Rolland.

This variety ranges from New England to southeastern Minnesota, south to Georgia and Missouri. In Wisconsin it is found most commonly in the southern two-thirds of the state on wooded bluffs, in moist thickets, lowland woods, wooded ravines, along lake and river banks and sometimes in moist upland woods and cut-over coniferous and deciduous woods. It is less common than the following variety. Flowering May to June; fruiting mid-June to August.

10b. LONICERA DIOICA L. var. GLAUCESCENS (Rydb.) Butters Map 28.

Differs from var. *dioica* in having the *leaves pubescent beneath, the corolla villous and sometimes glandular externally* and hairy within and the *style hirsute.* Widely ranging from western Quebec to British Columbia, south to Ohio, Iowa and Oklahoma. The widespread variety in Wisconsin. Habitats, flowering and fruiting are similar to those of var. *dioica.*

11. LONICERA PROLIFERA (Kirchner) Rehder var. PROLIFERA Grape Honeysuckle Map 29.

Twining or climbing vine with glabrous twigs and glossy, pale-brown bark which is often peeling on the older branches. Leaves broadly oval to obovate, sessile or nearly so, 4-8 cm long and 2-4 cm wide, *rounded, obtuse or slightly notched at the tips* and tapering at the bases, *the upper surfaces green and more or less glaucous,* the lower surfaces pale, glaucous and glabrous to slightly appressed-puberulent, *the uppermost connate-perfoliate, forming an oval or subrotund disk with obtuse to retuse tips.* Flowers in 2-6 whorls on terminal spikes in the uppermost disks. Calyx obscurely 5-lobed, glabrous. Corolla pale yellow, 2.5-3 cm long, slightly gibbous at the base, the tube equalling or slightly longer than the lobes, glabrous externally, hairy within. Stamens exserted, the filaments slightly hairy. Ovary glabrous; style slightly hairy to nearly glabrous. Fruit a red berry. 2N = 18.

Chiefly south of the Tension Zone where it is locally common along the margins and in open oak and maple woods, logged-off woods, wooded hillsides, talus slopes, bluff tops, sometimes in thickets and along brushy stream banks, and rarely along edges of marshes and bogs and in open pine woods. Flowering mid-May to July; fruiting mid-July to October.

12. LONICERA HIRSUTA Eat. var. INTERIOR Gl. Hairy Honeysuckle Map 30.

Climbing vine with hirsute twigs and smooth grayish-brown bark which becomes shreddy on older branches. Leaves broadly elliptic to oval, 5-12 cm long and 3-8 cm wide, dull green and *sparsely to densely appressed-puberulent on the upper surfaces,* downy-pubescent and paler or sometimes grayish beneath and with *ciliate margins,* the lower with acute tips and rounded to acute bases, with *short petioles,* the upper one or two pairs connate-perfoliate, the *terminal pair forming a rhombic to elliptic or nearly orbicular disk, with abruptly acuminate tips.* Flowers in 2-several whorls on short-peduncled terminal spikes. Calyx obscurely 5-lobed. Corolla 10-18 mm long, pale yellow to orange, slightly gibbous at the base, 2-lipped, the lobes nearly equal to the tube in length, more or less glandular-pubescent externally and hairy within. Stamens exserted; filaments hairy. Ovary glabrous or sparsely glandular; style somewhat hairy. Fruit a red berry. 2N = 18.

A species of the northern hardwood forest, ranging from Quebec and New England to Saskatchewan, south to Pennsylvania, northern Michigan, Wisconsin and Minnesota. In Wisconsin it is found north of the Tension Zone on calcareous, quartzitic, granitic and morainic sandy soils in maple-birch-white pine forests, in cut-over areas regenerating to aspen-birch woods, sometimes in low, moist aspen woods and occasionally in open areas along stream banks and margins of bogs. Flowering June to August; fruiting August to September.

The Trumpet Honeysuckle, *Lonicera sempervirens* L. a glabrous high-climbing vine is sometimes planted in southern Wisconsin for its showy scarlet-orange, nearly regular, tubular, flowers which are 3.5 to 8 cm long. There are no records of its establishment outside of cultivation.

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DROUGHT IN WISCONSIN

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Abstract

Drought in Wisconsin is not as uncommon as the abundant agriculture and the beautiful greenery of the state might suggest. Both agricultural and hydrologic droughts, as defined by a simple precipitation criterion, occur in some part of the state on the average of once in about seven years. Statewide drought occurs less frequently. There appears to be no cyclical pattern to drought occurrence in Wisconsin.

INTRODUCTION

Drought is a word that brings to mind parched land, desicated crops and blowing soil. This, of course, is often the result of severe or extreme drought. However, drought need not be extreme to be important.

In this paper, two types will be considered, hydrologic and agricultural drought. Hydrologic drought affects stream flow and lake and water table levels. Agricultural drought comes at a time and intensity to affect crop production. Both types may, but need not, occur simultaneously.

The effects of hydrologic drought result from integrated changes in precipitation over a moderately long time period. As a result, annual precipitation is used here as an index of hydrologic drought. For agricultural drought, rainfall from May through August is used as an approximation of the growing season precipitation. Droughts are not limited to a growing season nor to the calendar year, but vary in timing and length. However, for an initial look at Wisconsin drought, these two periods proved to be meaningful.

APPROACH

The term drought is difficult, if not impossible, to define precisely because it deals with one end of a precipitation continuum along which there are no breaks that make division into wet and dry periods possible. In this paper, no all-inclusive definition of drought will be attempted, but rather a simple approach to drought based on an analysis of mean precipitation and variability about that mean is used.

The determination of drought used in the following discussion is based on the years 1904 through 1977. This period is the longest for which continuous precipitation records are available for the 18 stations considered (Fig. 1). Drought is defined as a period (either annual or May-August) when the precipitation for a specific location is equal to or less than the mean precipitation minus one standard deviation. For example, the annual mean precipitation of the Antigo station is 30.30 inches and the standard deviation is 5.29. Thus, any year in which the precipitation is equal to or less than 25.01 inches would be considered a hydrologic drought year.

Basing a definition of drought on precipitation alone ignores important meteorological parameters such as temperature and wind as well as non-meteorological aspects of importance. However, this simple approach provides a beginning to the consideration of drought in Wisconsin.

Fig. 1. Locations of 18 precipitation recording stations (closed circles) used in this study.

Results

Graphs of annual precipitation for each of the 18 stations from the beginning of the period of record through 1977 all show certain characteristics. These characteristics are evident in Fig. 2 which represents a north-south transect across the state. A consideration of the graphs helps point out the similarities and the differences in the space and time variation of drought years.

Year to year variability in precipitation is relatively high in all parts of the state. Years with above average precipitation and years with below average precipitation are common. In some cases, there is a statewide correspondence in wet or dry years, but there are many more years where the wet or dry years are not correlated across the state. The four stations, of the 18 studied, presented here, represent the characteristics of the other 14 satisfactorily.

Over the period considered, hydrologic drought occurred at irregular intervals with an average of one statewide drought in 35 years. It is important to remember that the 35 year interval is only an average. Averages are often based on widely varying occurrences as is true in this case.

In growing season totals as in annual precipitation certain years stand out as

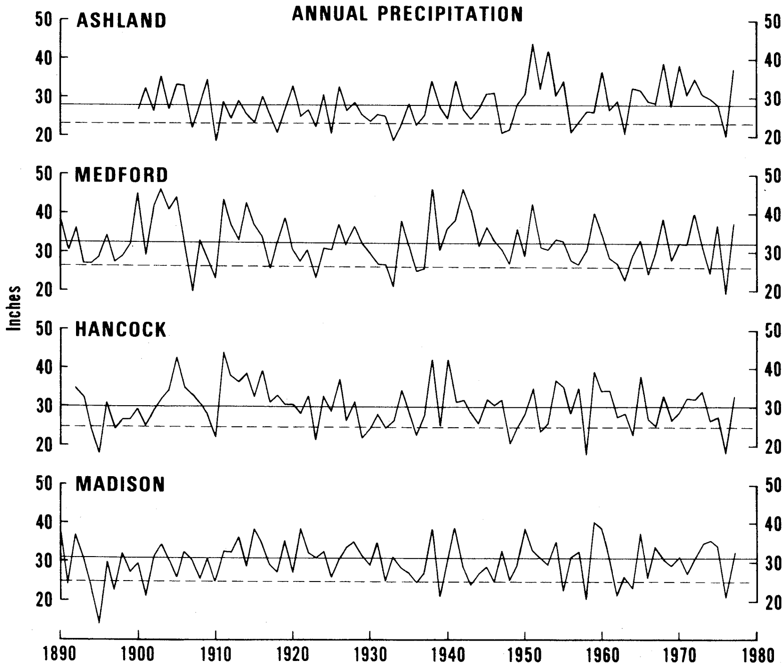

Fig. 2. North to South transect of annual precipitation showing 1904-1977 mean (solid line) and one standard deviation below the mean (dashed line). Years below the lower line have hydrologic drought.

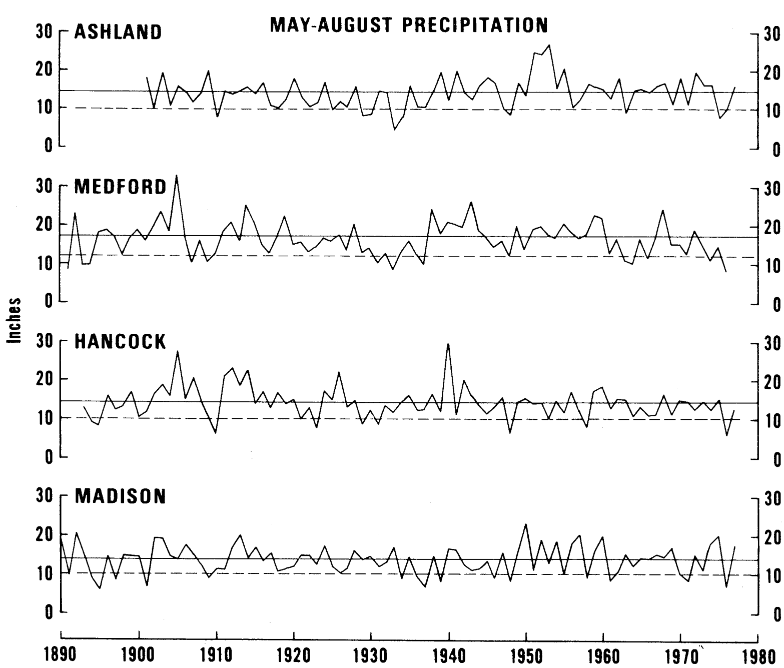

Fig. 3. North to South transect of May-August precipitation totals. Mean values (solid line) and values one standard deviation below the mean (dashed line) are shown. Years below the dashed line are years with agricultural drought.

drought years (Fig. 3). The most outstanding years with agricultural drought seasons occurring essentially statewide were 1895, 1910, 1929, 1936, 1937, 1943, 1963, and 1976. Some, but not all, of these years correspond to years of hydrologic drought. As for annual precipitation, in some years, the state responded as a unit or a whole, and in other years, only part of the state was affected.

It is evident that agricultural drought occurs more frequently than hydrologic drought. This suggests that the frequency of dry periods decreases as the length of the dry period increases.

Statewide similarity and variability may also be shown by graphing the percentage of stations undergoing drought in a given year. As a result of differences in the length of precipitation records, the number of stations used to compile the values will vary (Fig. 4). For the 1894-1899 period, 16 stations were used. Ashland was added in 1900 and Minocqua Dam was added in 1904 to bring the total to 18 stations from 1904 through 1977.

Figures 2, 3 and 4 convey two important facts, drought does occur in Wisconsin frequently enough to be highly significant and, drought may be statewide, but more commonly occurs in only a part of the state in any given year or season.

As pointed out earlier, droughts are not limited to a single growing season or a given calendar year. In addition, the arbitrary definition of drought used here does not address the problem of a dry period that does not meet the criterion of the definition. Hence, only the extreme conditions are dealt with here. The frequency and timing of drought or near drought is well illustrated by the 1930's, a decade infamous for drought throughout much of the country, including Wisconsin. It is instructive to consider this decade in more detail although there were droughts in Wisconsin both before and after the 1930's. Drought was not uncommon during the 1885-1900 period (Fig. 4). However, because there was a smaller population and a less well developed agriculture, the droughts of that period are not as well documented as those of the 1930's.

The growing season of 1929 is included with the 1930's since over 50% of the 18 stations endured a drought during that growing season. Agricultural drought occurred in some parts of the state in nine of the eleven years considered (Fig. 4). However, agricultural drought was reasonably widespread

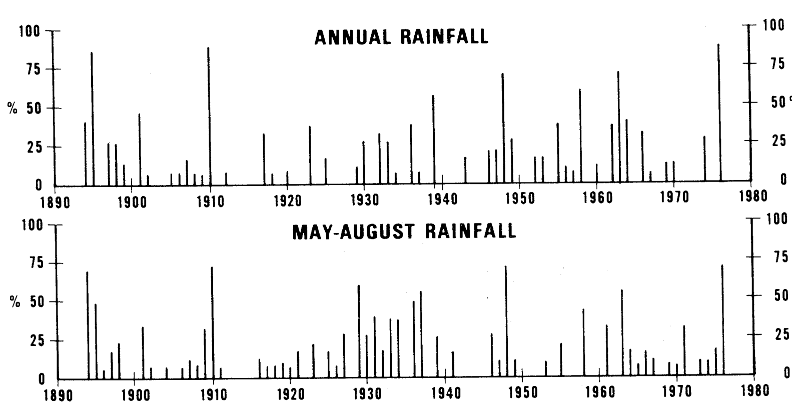

Fig. 4. Percentage of the 18 locations used that have either hydrologic or agricultural drought in a specific year.

in only three years—1929, 1936, and 1937. In those years, it affected approximately 50% of Wisconsin. During these eleven years, agricultural drought was more or less randomly distributed in both time and space. Locations varied experiencing droughts from only one to as many as five years during the period.

The 1930's also illustrate the occurrence of drought in a time frame different from that specified by a rigid definition. In Madison, 1936 with a total precipitation of 25.81 inches was not dry enough to meet the criterion for hydrologic drought. However, 1936 was a devastating drought agriculturally. This year is remembered in Madison and the surrounding area for both the severe dryness and the intense heat of July. A record high temperature for Madison, 107° F, occurred on July 14th. The drought began in March and lasted to mid-August. From March 1st through August 16th, 6.33 inches of precipitation fell, only 36% of the normal for that period. The drought ended when 5.22 inches of rain fell during the last half of August. This illustrates well the problem of considering drought over a specific period. Many more similar cases could be listed.

Summary and Conclusions

Although the climate of Wisconsin is one where precipitation is usually adequate for abundant crop production and to provide the state with many lakes and streams, drought is not uncommon. Using a simple definition of drought we can show that statewide hydrologic drought occurs on the average of about once in 35 years at irregular intervals. Droughts covering portions of Wisconsin are much more frequent. Although these limited droughts are more common than statewide drought, there appears to be no pattern in either time or space. No one part of the state experiences drought more frequently than another part. During the growing season each part of the state is hit by drought on the average of once in seven years, again there seems to be no cycle or pattern.

Acknowledgements

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T. C. CHAMBERLIN: THE KETTLE MORAINE AND MULTIPLE GLACIATION

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On the crest of Observatory Hill between Washburn Observatory and a bird effigy mound, stands Chamberlin Rock, a huge, pinkish gray boulder, that bears a plaque acknowledging Thomas Chrowder Chamberlin's contributions to Wisconsin:

> This tablet commemorates the services to Wisconsin of Thomas Chrowder Chamberlin, leader in science and education, State Geologist of Wisconsin, 1873-1882, President of the University, 1887-1892. As State Geologist he conducted a survey distinguished for high scientific and economic value. As President he made the spirit of research effective in the organization and life of the University. He first distinguished and named the drifts left in this region by successive ice advances. This boulder, brought by the continental glacier from ancient Pre-Cambrian bedrock in Canada, was deposited here in the Wisconsin, or latest glacial drift, of which this hill is a part.

T. C. Chamberlin (1843-1928) was an eminent American geologist. He enjoyed a distinguished career as scientific researcher, educator and government scientific administrator, and is best known for his glacial studies, the planetesimal hypothesis and the method of multiple working hypotheses.[1] Chamberlin's long and successful career began in Wisconsin.

The Chamberlin family, its possessions loaded in two prairie schooners and a small band of livestock in tow, arrived in Wisconsin when Thomas was two years old. Thomas's father, John Chamberlin, a farmer and a circuit-riding Methodist preacher originally from Camden County, North Carolina, had migrated westward with the frontier. He married Cecilia Gill in Palestine, Illinois in 1835. The Chamberlins settled on the Illinois prairie near present-day Mattoon, where, on September 25, 1843, Thomas was born. In 1845 the family moved again to escape malaria, then endemic to east central Illinois and elsewhere in the Mississippi River Valley. John Chamberlin purchased a one hundred and sixty acre homestead about four miles northwest of Beloit.

Wisconsin was still frontier when the Chamberlins arrived. Native prairie grassland and scattered oak openings covered most of southern Wisconsin and the prairie burned seasonally. A little farther to the north, Indians hunted and trapped in the woods and along the streams. Flocks of passenger pigeons darkened the sky during spring and fall migrations, and an occasional wolf came sniffing around the Chamberlins' new log cabin. The Chamberlins arrived in Beloit at about the time Beloit College was founded. The college received its charter from the territorial governor in 1846, and one of Thomas Chamberlin's earliest boyhood memories was of his father describing the ceremony of laying the cornerstone.

After Thomas and his four brothers attended the district grammar school, the Reverend John Chamberlin gave all his sons the opportunity to continue their education. The family moved temporarily into town as the Chamberlin boys began to enter Beloit's preparatory academy. Thomas entered the academy in 1858 and followed the prescribed curriculum of arithmetic, geography, English grammar, spelling, composition, reading, Greek and Latin.

In September, 1862 Thomas began the traditional course of Greek, Latin, and mathematics, with lesser amounts of philosophy, history, literature, and science, in the college. Young Chamberlin acquired a budding interest in science under the guidance of Professor Henry B. Nason, a chemist and mineralogist who had travelled widely and was familiar with American and European geology.[2] Chamberlin earned his college expenses teaching in county grammar schools in the vicinity of Beloit and nearby Rockford, Illinois. A country school teacher's compensation was uncertain however, as Chamberlin learned when a member of the Rockford district school board (who owned a nursery) persuaded the young teacher to take his salary in trees. Those he could not sell, Thomas planted on the family farm.[3]

Thomas Chamberlin graduated from Beloit College in 1866 and that fall became high school principal at nearby Delavan. There he instituted a series of "lecturettes" in the natural sciences and led his students into the nearby countryside on sunny afternoons so that they might learn to identify rocks, plants, and animals and observe their natural relations. The students became so enthusiastic over this innovation that the young schoolmaster frequently had to resort to textbooks to keep up with their curiosity. This experience made Chamberlin uncomfortably aware that his classical education had prepared him inadequately to teach the sciences, and after two years in Delavan he decided to undertake graduate study to broaden his foundation in science. Following a year at the University of Michigan studying geology under Alexander Winchell, Chamberlin returned to southeastern Wisconsin, in 1869, to teach natural sciences in the Whitewater State Normal School. During four years at Whitewater, Chamberlin strengthened instruction in the natural sciences and motivated several students toward careers in science teaching.

In 1873, Thomas Chamberlin returned to Beloit College, teaching geology, zoology, and botany until 1880, when the department was subdivided and he became Beloit's first Professor of Geology. Professer Chamberlin was regarded as a stern but inspiring and innovative teacher, and geology became a popular subject. As a teacher Chamberlin endeavored to focus on current geologic problems, stressing the broader aspects and the methods of the science. A favorite pedagogical practice was to take his classes to the cupola of the Middle College building and to ask his students then and there to write down their interpretation of the gently rolling, glacially contoured topography that lay below them. His advanced senior course included the microscopic study of thin sections of rocks with a polarizing microscope, then a relatively new technique being pioneered by Roland D. Irving.[4] Chamberlin conducted field work for the Wisconsin Geological Survey concurrently with his teaching. When professional geology began to absorb the greater portion of his energies, Chamberlin resigned the chair of geology at Beloit College in the spring of 1882, continuing as an occasional lecturer for five years.

Prior to statehood, David Dale Owen had surveyed Wisconsin's mineral resources in 1839-1840. Two other geological surveys of the state followed, one in 1853-1856 headed by Edward Daniels and J. C. Percival, and the second during 1857-1862 under the direction of New York state geologist James Hall.[5] In 1873 the legislature appropriated funds providing for a complete and systematic four-year geological survey of Wisconsin; the survey was later extended into 1879.

Chamberlin and fellow members of the Wisconsin Academy of Sciences, Arts and Letters were influential in securing political support for the 1873 survey. The Academy had been organized in 1870 with Chamberlin as one of its charter members. In the early years several of the prominent members were geologists, among them Wisconsin's versatile naturalist Increase A. Lapham, Chamberlin, and Roland Duer Irving, professor of geology at the University of Wisconsin (and nephew of the New York author Washington Irving).[6] When the state survey was organized, largely as a result of the lobbying of these men, I. A. Lapham was appointed state geologist, and R. D. Irving, T. C. Chamberlin, and Moses Strong were named as assistants. Lapham, through no fault on his part, was not reappointed, and in 1875 O. W. Wight, a political appointee, took charge of the survey. Wight lasted for one year and then was replaced by Chamberlin in February, 1876. Irving and Strong remained as assistant geologists.

Irving was responsible for surveying the ancient crystalline rock formations, including the Penokee iron and copper ores, of the north central portion of the state. He was assisted in his microscopic study of the Precambrian rocks during the closing years of the survey by a promising University of Wisconsin geology student (and future president of the University), Charles Van Hise. This work of Irving and Van Hise, as well as Chamberlin's own microscopic analysis of the state's sedimentary rocks, distinguished the Wisconsin survey as among the first to employ microscopic petrology.[7]

Strong was to survey the western part of the state, and particularly the economically important lead and zinc deposits in the southwest. At the time of the survey much of northern Wisconsin was heavily forested and sparsely populated. There were few roads. Field work was a rugged, occasionally hazardous undertaking. In 1877 Moses Strong drowned in the Flambeau River while attempting to negotiate a tricky stretch of rapids. After Strong's death, Chamberlin completed the final revision of Strong's reports for western Wisconsin. Like Josiah D. Whitney, geologist with James Hall's earlier survey, Chamberlin decided that the lead and zinc ores had originated as precipitates from the early Paleozoic seas. However, Chamberlin's interpretation differed from the previous one in his recognition of the role of ground water in concentrating the metals in economically significant amounts. Chamberlin proposed that the lead and zinc minerals had accumulated simultaneously with, and had originally been dispersed throughout, the layers of sediments. Later the minerals were deposited in cracks and fissures by ground water seeping through the sedimentary rocks after the area had risen above sea level.

As chief geologist, Chamberlin was responsible for compiling and editing the survey reports. In addition, he was personally responsible for the survey of southeastern Wisconsin. He began field work in that area as assistant geologist in 1873 and continued after his appointment as director in 1876. At the time of his field assignment, a friend commiserated, "Mr. Chamberlin, you are shelved. What is there to be found in southeastern Wisconsin?"[8] Compared to Irving's and Strong's assignments in areas of economically interesting ore rocks, Chamberlin's assignment seemed mundane. The lower Paleozoic sedimentary strata of southeastern Wisconsin were for the most part buried under unalluring heaps of glacial drift. But rather than shelved, Chamberlin became America's leading glacial geologist.

Southeastern Wisconsin was a particularly propitious area in which to study glacial geology. Most of Wisconsin, with the exception of the southwest corner, is covered with a veneer of loose, glacially transported boulders, gravel, and soils, called "drift" because, during the first half of the nineteenth century, geologists had thought that this material had been carried by flotillas of icebergs that had broken off from glaciers to the far north. These icebergs, it was assumed, had drifted over submerged areas of the continent, and dropped their embedded cargo of rocky materials as they thawed. By the time Chamberlin began his field studies, most of the drift was recognized as actual glacial deposits, rather than the jetsam of hypothetical icebergs.

The drift, also known as "ground moraine" or "till," had been spread over the surface as the ice sheet that had carried the rocks and soil melted and retreated. In Chamberlin's section of Wisconsin the glacial drift was deployed in an arcuate pattern of ridges. The ridges were known locally as the Potash Kettle Range because the drift contained many pits and kettle-like depressions of varying shapes and depths.[9] Occasionally the depressions were filled with water, forming kettle lakes. Chamberlin concluded that the Kettle Range was "evidently a gigantic moraine." The outermost ridge, or terminal moraine, marked the farthest advance into southern Wisconsin of the tongue of the continental ice sheet that had extended over Green Bay and the Fox River valley, south into the Rock River valley. Chamberlin remarked of this feature: "It is improbable that the whole glacial field, when fully explored, will offer a better type-example of the formation of a glacial tongue in open and comparatively plain country, and of the remarkable laws that governed its action, than did the little glacier of the Green Bay-Rock River Valley, one of the least among its brethren."[10] Another tongue of the ice sheet had extended the length of the Lake Michigan basin, lapping over the eastern edge of Wisconsin. The main, roughly north-south section of the Kettle Range included the moraine formed along the western edge of the Lake Michigan ice lobe and the moraine marking the eastern edge of the Green Bay lobe. Chamberlin termed this range of moraines, formed intermediate between two glacial tongues, an "interlobate" moraine.[11]

Chamberlin considered the Kettle Moraine to be "a peculiar and irregular aggregation" of the widespread ground moraine, and thought at first that the ridges and hills formed when the ice had halted in the midst of its retreat and readvanced, plowing the materials it had deposited into immense ridges. He supposed the series of more or less parallel ridges could be explained by alternating retreats and readvances of the ice repeated several times.[12] The kettles were formed as large remnant blocks of glacial ice incorporated within the drift melted, leaving a depression.[13] Chamberlin also suggested that they might represent original irregularities in the surface of the drift or be the result of a sinking and settling of the drift material in places where loose sandy material had been carried away by under-drainage.[14]

The state geologist studied the striae caused by rocks frozen into the bottom of the glacier scraping over the bedrock surfaces, and from the orientation of these scratches and grooves parallel to glacial motion was able to determine the direction of ice movement within the two glacial lobes. The movement of the ice had been generally south and southwestward, parallel to the axes of the ice lobes and to the trend of the present basins formerly occupied by the ice. However, as the ice had fanned outward from the axes of the lobes, its movement had been directed at right angles to the margins of the lobes. Thus the striae on the bedrock in the peripheral glaciated areas were generally oriented perpendicular to the moraines.[15] Other features that Chamberlin used in interpreting ice movement were the elongated, somewhat "whale-shaped" hills of unsorted drift known as drumlins. The axes of the drumlins tend to parallel the flow of the ice that shaped them and their steeper ends face in the direction from which the ice came. The distribution of boulder trains also indicated the direction of ice flow. The boulders in these 'trains' were of native Wisconsin bedrock, unlike the many erratics brought into the state by the ice, and could be traced to certain distinctive local source areas. The ice, as it passed over these source areas, dislodged weathered chunks of the rock and carried them away, 'downstream' from their source, and then abandoned the boulders as it retreated. Quartzite boulder trains, strewn in a generally southwesterly direction as far as

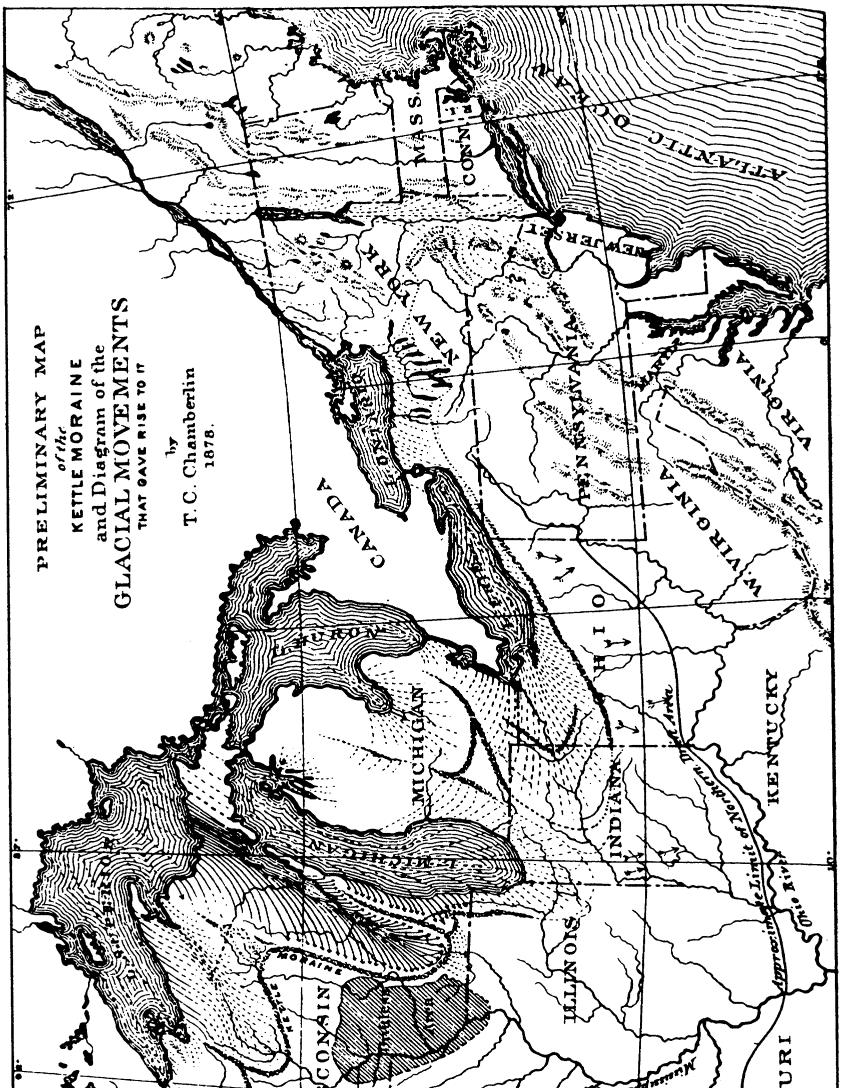

Fig. 1. Preliminary map of the Kettle Moraine and diagram of glacial movements. (From T. C. Chamberlin. 1878 Trans. Wis. Acad. Sci. Arts and Letters, Vol. IV, p. 208.)

sixty miles from their source near Waterloo, where the quartzite outcrops, indicated to Chamberlin that ice movement there had been from northeast to southwest. Southeastern Wisconsin drift was also characterized by kames—moundlike hills of sorted drift deposited by flowing melt-water in openings in, or on the surface of, stagnant ice or against the margin of the ice sheet; and eskers (Chamberlin used the Scandinavian term "osar" in his early writings)—long, serpentine ridges of drift deposited by meltwater flowing through tunnels at the base of the ice.

In 1878 Thomas Chamberlin was sent to Europe as Wisconsin's delegate to the Paris Exposition. During this visit he presented a paper on his glacial studies to the International Geological Congress and took advantage of the opportunity to observe Alpine glaciers and their associated phenomena. While distinguishing important differences between the phenomena produced by glaciers confined to narrow mountain valleys and those produced by a massive continental ice sheet, Chamberlin noted certain aspects of Alpine glaciation that seemed roughly analogous to some features of Wisconsin's drift.[16] In particular, the "Jardin" in the Chamonix region of the French Alps, an area that was free from ice though surrounded by active glaciers, reminded Chamberlin of Wisconsin's driftless area. Chamberlin later made a detailed study of the driftless area with his associate and former student at Beloit, Rollin Salisbury.[17] Unlike the Alpine Jardin which stood above the bordering glaciers, the driftless area in southwestern Wisconsin, southeastern Minnesota, and northeastern Iowa lay in the Mississippi Valley with higher land to the north. Chamberlin concluded that . . . "Diverted by highlands, led away by valleys, consumed by wastage where weak, self-perpetuated where strong, the fingers of the mer de glace closed around the ancient Jardin of the Upper Mississippi Valley, but failed to close upon it."[18] The driftless area provided a standard of comparison particularly valuable because the bedrock formations of the driftless area were the same as those underlying the surrounding glaciated region. The driftless area suggested how the preglacial surface of the glaciated region may have appeared, thus providing Chamberlin with a means for better judging the work of the ice.

In his discussion of Wisconsin glaciation for the state survey reports Chamberlin had concerned himself with the moraine only as it occurred in the state. In a paper prepared for the Wisconsin Academy of Sciences, Arts and Letters, he pointed out that Wisconsin's Kettle Moraine was but the local segment of the great moraine which had bordered the lobate edge of the former vast North American ice sheet (Fig. 1).[19] He observed that this entire moraine was not necessarily coincident with drift marking the farthest extent of the ice, and hinted at the possibility of two separate stages of glaciation in North America.

> If the evidence adduced to show that the Kettle moraine was due to an advance of the glaciers be trustworthy, then, to the extent of that advance, whether much or little, the moraine marks a secondary period of glaciation, with an interval of deglaciation between it and the epoch of extreme advance. Its great extent indicates that whatever agency caused the advance was very widespread, if not continental in its influence. The moraine, therefore, may be worthy of study in its bearings upon the interesting question of glacial and interglacial periods.[20]

The Scottish geologists James Geikie and James Croll had already suggested that there had been more than one episode of glaciation in Europe.[21] In Scotland, Geikie had found marine sediments containing shells, fresh water deposits, and vegetal soils interstratified with glacial tills containing the bones of arctic mammals, indicating that the glacial conditions during which the tills had been deposited had been interrupted at least once, and perhaps several times, by submergence and milder climates. Croll related the occurrence of glaciation to periodic episodes of maximum eccentricity in the earth's orbit.

Evidence suggesting two occurrences of glaciation had been accumulating gradually in the United States. As Chamberlin noted, there was the distinct terminal moraine to the north, while the drift south of the moraine had a more weather-worn appearance, suggesting that it had been subjected to erosional processes longer than the drift bounded by the moraine. More convincing were the "forest beds," layers of decayed vegetable matter found buried between two distinct sheets of glacial drift at various locations.[22] These forest beds and layers of soil suggested that the ice had been absent and the climate had been warm enough for forests to grow upon the lower till before the next ice advance. Despite this evidence, the interpretation involving alternating glacial and interglacial phases was not readily received in the United States. Chamberlin explained in volume one of the *Geology of Wisconsin* (1883), the fourth and last volume of the state survey reports to be published, that he had not formally advocated the hypothesis of multiple glaciation in previous volumes "due partly to the fact that investigations were still in progress, which made it injudicious to prejudice results by broad conclusions in advance of the fullest available data, and partly to the fact that the existence of two such periods had not been generally recognized by American geologists, although the doctrine of separate glacial periods had been entertained by several in this country, following the lead of the Scotch school."[23] Chamberlin, as a result of an extended survey of the moraine, became more firmly convinced that there had indeed been two episodes of glaciation in North America.

> Our present firmness of conviction arises (1) from the discovery and working out of an extended moraine stretching across the whole of the glaciated area and belonging to a system of glacial movements which differ in many important respects from the earlier ones; and (2) from the differences of surface contour due to the greater erosion of the earlier, as already indicated. We believe that this line of evidence, when developed in its fulness, will prove entirely demonstrative. Only a small part of the results now gathered fall specifically within our present province as chronicler of the geological history of Wisconsin, but the total result is, in some important measure, the outgrowth of investigations begun in this State.[24]

Field work for the Wisconsin Geological Survey ended in March, 1879, but Chamberlin continued his editorial duties into 1882. The reports formed an impressive four-volume description and interpretation of Wisconsin's natural resources with practical suggestions for their utilization. The exemplary character of the survey reports, Chamberlin's successful administration of the survey, and his particular interest in glacial phenomena attracted the attention of John Wesley Powell, Director of the United States Geological Survey. In 1881 Powell appointed Chamberlin to head the new glacial division of the USGS. Chamberlin hired as an assistant Rollin D. Salisbury, a geology student from Beloit College, thus beginning a close professional association that was to last forty years.[25] R. D. Irving was given charge of the USGS Lake Superior division in 1882. Irving retained Charles R. Van Hise as his assistant and together they continued their pioneering microscopic study of the Precambrian rocks. Following Irving's death six years later, Van Hise succeeded his mentor as head of the division and rose to national prominence as a metamorphic geologist.[26]

Chamberlin's first undertaking was the detailed survey and mapping of the entire extent of the drift, from the Atlantic coast across the Midwest and Dakota Territory into Montana. He spent field seasons tracing what he considered the more or less continuous, looping "terminal moraine" which marked the former position of the multilobate edge of the ice sheet, the same formation he had correlated with Wisconsin's Kettle Moraine. As a result of these field studies, Chamberlin became intimately familiar with the wide range of Pleistocene phenomena. Early in this survey he corroborated his Wisconsin observations and their suggestion of two glaciations in North America. Chamberlin's first report was titled "Preliminary Paper on the Terminal Moraine of the Second Glacial Epoch."[27]

After 1882 Chamberlin pursued U. S. Geological Survey work full time, occasionally teaching at Columbian (now George Washington) University in Washington, D.C. In 1887, he returned to Wisconsin to become President of the University. He continued his research and his administration of the USGS glacial division while successfully guiding the growth of the University of Wisconsin. President Chamberlin's five-year administration is credited with strengthening organization, curriculum, and faculty, and accomplishing the transition from a college to a true university.[28] In 1892, to devote more time to teaching and geological research, Thomas Chamberlin became head of the Department of Geology at the new University of Chicago.

As a result of the investigations of the USGS Pleistocene division, which included the field work of such able assistant geologists as R. D. Salisbury, Warren Upham, Frank Leverett, and William Alden, it became apparent that North American glacial history was indeed complex. One of the major problems facing American glacial geologists was the correlation of midwestern glacial deposits with those in the East. As Chamberlin had noted during the course of his earlier Wisconsin studies, the extreme border of the drift, was not coincident with the terminal moraine. This divergence of the moraine from the drift border was particularly apparent in the Midwest where the moraine, after forming the loop that outlined the Green Bay lobe of the ice sheet, crossed Wisconsin north of the driftless area, entered Minnesota, dipped into north central Iowa and continued northwestward across northeastern Nebraska. Yet drift material could be found beyond the morraine as far south as north central Missouri and northeastern Kansas. However, east of Ohio the discrepancy between the moraine and the southernmost extent of the drift was not so remarkable, nor was the lobate pattern of the moraine conspicuous in its eastern reaches. While Chamberlin recognized, in the weathered drift south of the moraine, evidence of an earlier glaciation, with the moraine delimiting the drift of a second more recent ice advance, geologists in the East were more inclined to interpret the eastern drift as evincing only one major glaciation, with perhaps minor oscillations in the position of the ice front.

The drift in Pennsylvania had been surveyed by Henry Carvill Lewis and George Frederick Wright. Following the death of Lewis, Wright, a professor of theology at Oberlin College and an enthusiastic self-taught geologist, continued the work as a member of Chamberlin's USGS Pleistocene group. Wright thought that drift found beyond the distinct drift border that Chamberlin had identified as the "terminal moraine" in northwestern Pennsylvania was merely a "fringe" deposited by the same ice sheet that had left the moraine, with the moraine itself marking where the ice front had halted for a considerable period of time. Chamberlin contended that the moraine-bordered drift and Wright's extramorainal "fringe" indicated two "somewhat widely separated epochs of glaciation."[29] At issue were whether the difference in character and position between the moraine-bordered drift and the extramorainal drift represented a full-scale retreat or a minor "oscillation" of the ice front, the amount of time involved, and whether the retreat of the ice had been accompanied by a significant change in climate. Wright argued that the forest beds of the Midwest, accepted by Chamberlin and others as evidence of a considerable interglacial interval of warmer climate, represented forests that had grown along the margin of the ice sheet, much as conifer forests grow near valley glaciers in Alaska. Chamberlin correlated river terraces and gravels in the Mississippi and Ohio valleys with two episodes of glaciation, and the erosion of the major portion of the valley trenches between upper and lower level terraces with the interglacial interval. Wright thought the drainage features and gravel terraces of the Ohio River valley could be attributed to one episode of glaciation and the presence, during much of the Pleistocene epoch, of a huge lake behind a hypothetical ice dam in the vicinity of Cincinnati. In addition, the chief of the Pleistocene division and the Oberlin theologian differed significantly in their broad conceptions of the ice age. Wright assumed that the glacial epoch had commenced perhaps one hundred thousand years ago (when a hypothetical elevation of the continent triggered climatic cooling) and a gradual spread of the ice sheet, with the ice dominating North America for a scant twenty-five thousand years. Wright's ice age was relatively brief, relatively recent, and one continuous event. Chamberlin believed that the glacial epoch had been multiple in nature and of much greater duration.

Upon completing his field studies, Wright promptly set about writing a popularized account of the ice age in North America, aspiring to emulate James Geikie's European work, *The Great Ice Age and Its Relation to the Antiquity of Man*. Chamberlin attempted to discourage him, because he questioned Wright's scientific abilities, suspected Wright of fame-seeking motives, and believed that North American Pleistocene research was not yet far enough advanced to supply a definitive account of the ice age. Chamberlin undoubtedly also assumed, and not altogether unjustly, that if a generalized history of North American glaciation were to be written, he was the one best qualified to do it. Nevertheless, Wright's *Ice Age in North America and Its Bearing upon the Antiquity of Man* was published in 1889, attracted the popular interest that Chamberlin feared it would, and went through three editions in three years. In 1892 Wright produced a similar work, *Man and the Glacial Period*. Chamberlin was scathingly critical of Wright's efforts, both in his private correspondence to fellow geologists and in print.[30] In 1892, Wright also prepared a paper on the "Unity of the Glacial Epoch" which was critical of Chamberlin's advocacy of two glaciations.[31] Chamberlin responded with a defense of "The Diversity of the Glacial Epoch,"[32] and the great American glacial debate was launched. The disagreement over the nature of the glacial epoch between Wright and Chamberlin and their various supporters enlivened many sessions at geological meetings and resulted in many pages in geological journals. T. C. Chamberlin emerged as the foremost advocate of multiple glaciation among American geologists.[33]

James D. Dana, of Yale, the dean of American geologists in the late nineteenth century and editor of the *American Journal of Science,* suggested that the main difference among geologists in the glacial debate was geographical. Those who had done field work in the East seemed to favor unity, whereas geologists familiar with midwestern Pleistocene phenomena discerned at least two glacial epochs. Dana thought the underlying reason for this was meteorological. The higher elevation of the eastern region and proximity of the Atlantic Ocean would have produced great amounts of snow, Dana supposed, while in the drier Midwest more thawing and more retreats and advances of the ice would have occurred. Dana concluded that there had been only one continuous glacial epoch with greater variations in the position of the ice front having occurred in the Midwest.[34] Chamberlin replied to Dana that geologists only found one drift sheet in New England because the drifts of earlier glaciations had been overridden and buried under the most recent drift, whereas in the Midwest a series of several drifts was exposed to the south of the drift of the last glacial advance. If the different deployments of the drift in New England and in the Midwest were related to different meteorological conditions as Dana had suggested, then the greatest expansion of the drift should not have occurred, as it had, on the midwestern plains where climatic and topographic conditions were supposedly less favorable. Chamberlin wrote: "The inferiority of the drift of New England in extent, in massiveness, and in serial development is the feature that calls for explanation in adverse conditions rather than the magnificent deployment of the glacial series on the plains of the interior."[35]

In 1894 Chamberlin supplied a description of the North American Pleistocene succession for the revised third edition of James Geikie's *Great Ice Age,* in which he subdivided the drift into three glacial formations representing three stages of glaciation, with two intervening interglacial formations.[36] On this occasion Chamberlin for the first time proposed tentative names for the North American drift sheets. Employing geographic nomenclature, he suggested the name "Kansan" for the bottommost layer of drift deposited during the earliest ice invasion that had extended the farthest southwestward into Kansas. The Kansan till was overlapped by another sheet of drift which Chamberlin christened the "East Iowan." Between this second drift and the older Kansas till were a well-developed soil horizon and forest beds. As the name implied, the East Iowan drift was most characteristically displayed in northeastern Iowa, and like the Kansan, was not usually bordered by any definite terminal moraine. Above the East Iowan drift sheet was a second horizon of soils, peat, and vegetal accumulations indicating another noteworthy interval of deglaciation. Further evidence of such an interval was the generally eroded topography of the surface of the East Iowan drift. In addition, fossiliferous strata containing a moderate-climate flora and fauna sandwiched between glacial deposits had recently been reported near Toronto, Canada, indicating a significant retreat rather than a minor oscillation of the ice front.[37] Chamberlin tentatively correlated these fossiliferous beds with the soils overlying the East Iowan drift. Topping off the North American Pleistocene sequence was the complex, moraine-bounded drift which Chamberlin named the "East Wisconsin." Chamberlin subsequently shortened the names of the two younger drifts to "Iowan" and "Wisconsin" and suggested locale names for the interglacial deposits. The forest bed between his Kansan and his Iowan tills was named the "Aftonian," for its exposure at a railway excavation near Afton Junction, Iowa. The second interglacial formation between the Iowan and Wisconsin drifts was called the "Toronto" formation.[38]

Meanwhile the glacial drift of the upper Mississippi Valley was being subjected to detailed scrutiny by Samuel Calvin and H. Foster Bain of the Iowa Geological Survey and by Frank Leverett, one of Chamberlin's assistants, in Illinois. Previously, W J Mc Gee of the United States Geological Survey had distinguished a lower till and an upper till separated by a forest bed in Iowa. Under Chamberlin's classification these became the Kansan drift sheet, the Aftonian interglacial beds, and the Iowan drift. During 1895 and 1896 Calvin and Bain sorted out a third till sheet and a second forest bed in northeastern Iowa. The Iowa geologists applied the term "Iowan" to the newly differentiated uppermost till sheet and shifted the term "Kansan" to the till sheet that Chamberlin had named "Iowan." During this time Frank Leverett had discerned a drift sheet in Illinois referable to a separate stage of glaciation. Leverett traced the Kansan drift across the Mississippi River into Illinois where it lay underneath the "Illinoian" drift, and in turn had traced his Illinoian drift sheet west across the Mississippi into Iowa where it underlay the new Iowan drift. Thus by 1896 there seemed to be five distinct North American glacial formations: 1) the sub-Aftonian drift sheet (Chamberlin's original Kansan), overlain by the Aftonian interglacial beds; 2) the Kansan drift (Chamberlin's original Iowan), separated by an interglacial deposit from 3) Leverett's Illinoian drift sheet, above which were more interglacial soils; 4) the Iowa geologists' Iowan drift, overlain by an interglacial deposit which possibly corresponded with the Toronto interglacial fossil beds; and 5) the complex Wisconsin drift.

Chamberlin went over parts of central Iowa with Assistant State Geologist H. Foster Bain, who was at the time working up a section of that area for his doctoral dissertation under Chamberlin, and in 1896 Chamberlin was willing to accept the transfer of the Kansan and Iowan terms with only slight reluctance.[39] However, he later came to regret this change in nomenclature and wished to re-establish his original designations. His original Iowan till, the Kansan of the Iowa geologists, seemed to Chamberlin to be more distinctively displayed in Iowa than elsewhere and to be the most extensive and typical of Iowa's drifts.[40] But the patriarch of American glacial geology was not heeded by the younger generation of geologists. Chamberlin's Iowan drift became the Kansan and the lowest, sub-Aftonian till sheet was renamed the "Nebraskan" drift. The name Iowan was applied to the till sheet between the Illinoian and Wisconsin drifts. Leverett named the upper three interglacial intervals the "Yarmouth," between the Kansan and Illinoian drifts, the "Sangamon," between the Illinoian and Iowan drifts, and the "Peorian," between the Iowan and Wisconsin drifts. In the early twentieth century, Geikie's six European glacial epochs were trimmed to four stages and the comparatively insignificant drift of northeastern Iowa, which brought the number of North American glacial formations to five, became an embarrassing anomaly. Although Thomas Chamberlin did not live to see it, this Iowan till sheet later was demoted from a formation representing a major ice invasion to a substage of the Wisconsin glaciation, leaving Iowa, though covered by several tills, with a namesake in none of them.[41]

For the quarter of a century following his appointment as head of the United States Geological Survey Pleistocene division, Thomas Chamberlin dominated American glacial geology. After the turn of the twentieth century, Chamberlin's research focused less on glacial problems and more on the circumstances surrounding the origin of the Earth. During the 1890's Chamberlin became interested in theories of climatic change and the causal factors of the glacial epoch. His attention was drawn to the possibility that a decrease in the amount of carbon dioxide in the atmosphere had lowered the earth's ability to retain heat and may have led to a glacial climate.[42] Periods of low atmospheric carbon dioxide content would correlate with periods of glaciation. Chamberlin suggested a mechanism which might cause atmospheric carbon dioxide to fluctuate. During the chemical weathering of silicate rocks atmospheric carbon dioxide combines with minerals to form new carbonate compounds. Chamberlin assumed that this was the chief process by which carbon dioxide was subtracted from the atmosphere and locked up in the earth's crust. The erosion of massive continental areas following a major uplift would deplete the atmospheric store of carbon dioxide and lead to cooling. An additional factor was the ocean's ability to act as a reservoir of carbon dioxide: the colder the ocean, the more carbon dioxide it can hold. Then, as ice sheets covered large areas of crystalline silicate rocks, the carbonation process would be halted, depletion of atmospheric carbon dioxide would be curtailed, the cooling trend would be reversed, and glaciers would retreat. As the ice melted and the crystalline rocks were again exposed, atmospheric erosion and carbonation would recommence and another stage of glaciation would occur. Alternating glacial and interglacial phases would continue until erosion brought continental areas low, the rate of weathering processes slowed, and shallow seas crept over the continental margins providing a habitat for marine organisms that secreted calcareous skeletons. During the organic lime-secreting process carbon dioxide is removed from sea water and released to the atmosphere. According to Chamberlin, the lime-secreting activities of myriads of marine organisms would contribute a sufficient amount of carbon dioxide to the atmosphere to effect a warming trend. A mild subtropical climate would ensue until a large-scale tectonic uplift again exposed vast continental areas.[43]

Chamberlin's consideration of the interaction of the earth's crust, atmosphere, and oceans led him deeper and deeper into geologic history. In conjunction with his study of climatic change Chamberlin proposed a new hypothesis for the origin of the earth—the planetesimal hypothesis—and developed it over a period of twenty-five years in association with the astronomer Forest R. Moulton. At the time of Chamberlin's death in 1928 the planetesimal hypothesis ranked as a major twentieth-century cosmogony. As Chamberlin had remarked, "the cold trail of the ice invasion had led by this long and devious path into the field of genesis."[44] For Thomas Chamberlin, this path began in the Wisconsin Kettle Moraine.

Notes

[1] Biographical material on Chamberlin can be found in Rollin T. Chamberlin, "Thomas Chrowder Chamberlin, 1843-1928," *National Academy of Sciences Biographical Memoirs,* 15 (1934): 305-407; George L. Collie and Hiram D. Densmore, *Thomas C. Chamberlin, Ph.D., Sc.D., LL.D. and Rollin D. Salisbury, LL.D. A Beloit College Partnership* (Madison: State Historical Society of Wisconsin, 1932); Carroll L. Fenton and Mildred A. Fenton, *Giants of Geology* (Garden City: Doubleday and Co., 1952), pp. 302-317; Kirtley F. Mather, "Thomas Chrowder Chamberlin," *Dictionary of Scientific Biography,* vol. 3, pp. 189-191; Bailey Willis, "Memorial of Thomas Chrowder Chamberlin (1843-1928)," *Bulletin of the Geological Society of America* 40 (1929): 23-44; Herbert C. Winnik, "Science and Morality in Thomas C. Chamberlin," *Journal of the History of Ideas* 31 (1970): 441-456; Susan Schultz, "Thomas C. Chamberlin: An Intellectual Biography of a Geologist and Educator" (Ph.D. dissertation, University of Wisconsin, 1976). In addition, the May-June, 1929 issue of the *Journal of Geology,* vol. 37, pp. 289-392 contains several articles on various aspects of the life and work of Chamberlin, and a bibliography of his works.

[2] Thomas C. Chamberlin, Memorial editorial on Henry B. Nason, *Journal of Geology* 3 (1895): 342-343.

[3] For Chamberlin's student days and later teaching career at Beloit College, see Collie and Densmore, *Chamberlin and Salisbury.*

[4] T. C. Chamberlin, "Roland Duer Irving," *Trans. Wisc. Acad.* 8 (1892): 433-437.

[5] See Ernest F. Bean, "State Geological Surveys of Wisconsin," *Trans. Wisc. Acad.* 30 (1937): 203-220 and Walter B. Hendrickson, "Nineteenth-Century Geological Surveys: Early Government Support of Science," *Isis* 52 (1961): 357-371.

[6] Chamberlin later noted that thirty-five per cent of the papers presented during the first two years of the Academy's existence were on geological topics ("The Founding of the Wisconsin Academy of Sciences, Arts and Letters," *Science* 52 [1920]: 7).

[7] George P. Merrill, *Contributions to a History of American State Geological and Natural History Surveys,* United States National Museum Bulletin 109 (Washington, D.C.: Government Printing Office, 1920), pp. 531-532; Louis V. Pirsson, "The Rise of Petrology as a Science," in *A Century of Science in America,* ed. E. S. Dana, New Haven: Yale University Press, 1918), p. 255; T. C. Chamberlin, "Charles Richard Van Hise," *National Academy of Sciences Memoirs* 17 (1924): 145; Maurice M. Vance, *Charles Richard Van Hise, Scientist Progressive* (Madison: State Historical Society of Wisconsin, 1960), pp. 24-25.

[8] R. T. Chamberlin, "Chamberlin," *Biographical Memoir,* p. 312.

[9] The term "potash kettle" refers to the large vessel commonly used in the frontier process of

obtaining potash, a crude form of potassium carbonate, used in making soap. Wood ashes were lixiviated (leached) and the solution was evaporated over a fire in large iron pots, yielding the potassium carbonate as, literally, pot ash.

[10] Chamberlin, "Preliminary Paper on the Terminal Moraine of the Second Glacial Epoch," *United States Geological Survey Third Annual Report* (1882), p. 315.

[11] Chamberlin, "Preliminary Paper on the Terminal Moraine," pp. 301-302.

[12] Chamberlin, T. C., *Geology of Wisconsin, Survey of 1873-1877,* 4 vols. and atlas (Madison: Commissioners of Public Printing, 1877-1883), 2: 214. When Chamberlin later visited Greenland as geologist with the Peary auxiliary relief expedition in 1894 and observed glaciers in action, he realized that moraines are not the result of plowing action on the part of the ice, but rather that the debris carried within the ice accumulates as the ice at the glacial margin melts and sloughs off its load of boulders, gravel, and soil while the ice front is stationary. When the ice front readvances, it does not plow the debris, but rides over it ("Recent Glacial Studies in Greenland," *Bulletin of the Geological Society of America* 6 [1895]: 214).

[13] This interpretation, the currently accepted explanation of true kettles, had previously been advanced by Charles Whittelsey in "On the Drift Cavities, or 'Potash Kettles' of Wisconsin," *Proceedings of the American Association for the Advancement of Science* 13 (1860): 297-301.

[14] Chamberlin, *Geology of Wisconsin,* 2: 214.

[15] Chamberlin later made a comprehensive study of glacial striae, "The Rock-Scorings of the Great Ice Invasions," *USGS Seventh Annual Report* (1885-1886), pp. 147-248.

[16] Chamberlin, "Observations on the Recent Glacial Drift of the Alps," *Trans. Wisc. Acad.* 5 (1877-1881): 258-270.

[17] Chamberlin and Rollin D. Salisbury, "Preliminary Paper on the Driftless Area of the Upper Mississippi Valley," *USGS Sixth Annual Report* (1884-1885), pp. 205-322.

[18] Chamberlin and Salisbury, "Driftless Area," p. 322.

[19] Chamberlin, "On the Extent and Significance of the Wisconsin Kettle Moraine," *Trans. Wisc. Acad.* 4 (1876-1877): 201-234. This paper was apparently first presented in 1875.

[20] Chamberlin, "Wisconsin Kettle Moraine," pp. 233-234.

[21] James Croll, "On the Physical Cause of the Change of Climate During Geological Epochs," *Philosophical Magazine* 28 (1864): 121-137; James Geikie, "On Changes of Climate During the Glacial Epoch," *Geological Magazine* 8 (1871): 545-553; 9 (1872): 23-31, 61-69, 105-111, 164-170, 215-222, 254-265, and *The Great Ice Age,* 1st and 2nd eds., 1874 and 1877.

[22] In 1868 A. G. Worthen had described buried soils between two tills in Illinois. Between 1869 and 1874 Edward Orton, J. S. Newberry, and N. H. Winchell also described forest beds, a peat bog, vegetal material, and soils interstratified between two tills in Ohio and Minnesota and recognized these deposits as representing an interglacial interval. See Herman L. Fairchild, "Glacial Geology in America," *Proceedings of the American Association for the Advancement of Science* 47 (1898): 272; F. T. Thwaites, "The Development of the Theory of Multiple Glaciation in North America," *Trans. Wisc. Acad.* 23 (1927): 41-164; G. F. Kay and E. T. Apfel, "The Pre-Illinoian Pleistocene Geology of Iowa," *Iowa Geological Survey Annual Report* 34 (1929): 71-72; and R. F. Flint, "Introduction: Historical Perspectives," in *The Quaternary of the United States,* ed. H. E. Wright, Jr. and D. G. Frey (Princeton: Princeton University Press, 1965), p. 5. Thwaites has surveyed and chronologically summarized the literature pertaining to the concept of multiple glaciation in North America.

[23] Chamberlin, *Geology of Wisconsin,* 1: 271-272.

[24] Chamberlin, *Geology of Wisconsin,* 1: 272.

[25] For the teacher-student relationship between Chamberlin and Salisbury and their subsequently interrelated careers as geologists, see Collie and Densmore, *Chamberlin and Salisbury.*

[26] For Van Hise's career, see Vance, *Charles Richard Van Hise.*

[27] *USGS Third Annual Report* (1882), pp. 291-402.

[28] Merle Curti and Vernon Garstensen, *The University of Wisconsin. A History, 1848-1925,* 2 vols. (Madison: University of Wisconsin Press, 1949), 1: 534-560 and James F. A. Pyre, *Wisconsin* (New York: Oxford University Press, 1920).

[29] See G. Frederick Wright, *The Glacial Boundary in Western Pennsylvania, Ohio, Kentucky, Indiana, and Illinois* with an Introduction by T. C. Chamberlin, United States Geological Survey Bulletin no. 58 (Washington, D.C.: Government Printing Office, 1890).

[30] See for example, Chamberlin, "Geology and Archaeology Mistaught," *Dial* 13 (1892): 303-306 and "Professor Wright and the Geological Survey," *Dial* 14 (1893): 7-9. Chamberlin's papers are located in the Department of Special Collections, Joseph Regenstein Library, University of Chicago. The controversy broadened and

several articles and editorials attacking and defending Wright and his argument for man's presence in North America during the ice age appeared in the *Journal of Geology* (edited by Chamberlin), the *American Geologist,* and *Popular Science Monthly* in 1892 and 1893. For a discussion of this controversy over man's relationship to the glacial epoch in North America, see Schultz, S. Ph.D. dissertation, University of Wisconsin, 1976, "Thomas C. Chamberlin," Chapter IV.

[31] *American Journal of Science* 144 (1892): 351-373.

[32] *American Journal of Science* 145 (1893): 171-200.

[33] For additional papers relating to this issue, see Chamberlin, "Some Additional Evidences Bearing on the Interval Between the Glacial Epochs," *Trans. Wisc. Acad.* 8 (1888-1891): 82-86; G. F. Wright, "Continuity of the Glacial Period," *American Journal of Science* 147 (1894): 161-187; Chamberlin and Frank Leverett, "Further Studies of the Drainage Features of the Upper Ohio Basin," *American Journal of Science* 147 (1894): 247-283, 483. See also "Subdivisions or Unity of the Glacial Period," *Popular Science Monthly* 44 (1893): 279-280 and "Reviews of the Ice Age at the World's Congress on Geology," *American Geologist* 12 (1893): 223-231.

[34] James D. Dana, "On New England and the Upper Mississippi Basin in the Glacial Period," *American Journal of Science* 146 (1893): 327-330. See also Warren Upham, "Diversity of the Glacial Drift along Its Boundary,"*American Journal of Science* 147 (1894): 358-365 for a similar argument. In the fourth edition of his venerable *Manual of Geology* Dana does subdivide the glacial period into three "epochs," but Dana's "subdivisions" tend to de-emphasize and obscure the multiple nature of the glaciation. His early, middle, and later glacial "epochs" are actually one phase of advance and two phases of retreat separated by "a long halt" of the same, single ice sheet (*Manual of Geology,* 4th ed. [New York: American Book Company, 1895], p. 934). In these discussions of Pleistocene glaciation there seems to have been no consistent attempt to limit the use of the terms "period" and "epoch" to any strict stratigraphic time connotations. Hence glacial "period," glacial "epoch," and ice "age" were often employed indiscriminately and interchangeably. This may have contributed to the lack of agreement.

[35] Chamberlin, Editorial, *Journal of Geology* 1 (1893): 847-849, quotation from p. 849.

[36] Chamberlin, "Glacial Phenomena of North America," Chapters 51 and 52 in *The Great Ice Age* by James Geikie, 3rd ed. (London: Edward Stanford, 1894), pp. 724-775. In preceding chapters Geikie had recognized six distinct glacial epochs and five interglacial intervals in Scotland.

[37] A. P. Coleman, "Interglacial Fossils from the Don Valley, Toronto," *American Geologist* 13 (1894): 85-93, and "Glacial and Interglacial Deposits Near Toronto," *Journal of Geology* 3 (1895): 622-645.

[38] Chamberlin, "The Classification of American Glacial Deposits," *Journal of Geology* 3 (1895): 270-277.

[39] See Chamberlin, Editorial on the nomenclature of the glacial formations, *Journal of Geology* 4 (1896): 872-876.

[40] Chamberlin, Review of "Comparison of North American and European Glacial Deposits" by Frank Leverett, *Journal of Geology* 18 (1910); 473.

[41] Current Pleistocene nomenclature recognizes the following stages:

IV. Wisconsinan glacial (Chamberlin)
Sangamonian interglacial
III. Illinoian glacial
Yarmouthan interglacial
II. Kansan glacial (Chamberlin's original Iowan)
Aftonian interglacial (Chamberlin)
I. Nebraskan glacial (Chamberlin's original Kansan)

[42] A paper by Svente Arrhenius, "On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground,"*Philosophical Magazine* 5th ser., 41 (1896): 237-276, convinced Chamberlin that a sufficient depletion of the atmosphere's carbon dioxide content would be quantitatively adequate to initiate glacial conditions. The relationship between atmospheric carbon dioxide and the retention of heat had been demonstrated three decades earlier by the British physicist John Tyndall.

[43] Chamberlin, "A Group of Hypotheses Bearing on Climatic Changes," *Journal of Geology* 5 (1897): 653-683; "The Ulterior Basis of Time Divisions and the Classification of Geologic History," *Journal of Geology* 6 (1898): 449-462; "The Influence of the Great Epochs of Limestone Formation upon the Constitution of the Atmosphere," *Journal of Geology* 6 (1898): 609-621; "An Attempt to Frame a Working Hypothesis of the Cause of the Glacial Periods on an Atmospheric Basis," *Journal of Geology* 7 (1899): 545-584, 667-685, 751-787.

[44] Chamberlin, *Origin of the Earth* (Chicago: University of Chicago Press, 1916), p. 9.

100 YEARS OF WISCONSIN PUBLIC WATER SUPPLIES

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Abstract

Over 70% of Wisconsin population is served by public water-supply systems which provide water to Wisconsin people for more than a century. History of Wisconsin public water supplies began relatively late, compared to other states. In Wisconsin, the first system was built in the city of Milwaukee in 1873. By 1886, 19 more systems were installed. Since then the number of public supplies has grown steadily at an average rate of little over six systems per year, a rate which has been declining in the last decade. Especially rapid rate of growth was experienced in the periods of 1892-96, 1935-1942, 1946-49 and 1964-68. The rate of growth of the number of public systems and of the population served by these systems follows closely the rate of increase in Wisconsin's population. At present, there are well over 500 public systems which provide water of good quality to more than 70 percent of the state's population, comparing to merely 10 percent in 1878.

INTRODUCTION

In December 1974, 93rd Congress enacted PL 93-523—as an amendment to the Public Health Service Act, under Title XIV, Safety of Public Water Systems—to assure that the public is provided with safe drinking water. This Act, known as the Safe Drinking Water Act, is the first major U.S. legislation for water management which recognizes ground water as an indispensable part of the total national water resource. In June 1977, uniform federal drinking water regulations went into effect for the first time for every public water system. The U.S. Environmental Protection Agency, responsible for the implementation of the Act recognized that states must be allowed maximum flexibility to address their problems. Therefore, the states had the option to utilize the State Public Water System Supervision Program with the help of EPA grants. As of September 1, 1979, all but 6 states were involved in the program. In Wisconsin, the responsibility for the program was delegated, in March 1978, to the Department of Natural Resources that conducts a regular surveillance of all community water systems.

Wisconsin public water supplies have recently celebrated an unnoticed 100-year anniversary, and their significance and history is worth remembering. The importance of water, one of mankind's vital commodities, is generally underestimated and overlooked. Many people take their water supply for granted and regard it as a common holding, similar to electricity, gas, or telephone utilities. They expect water to be instantly available in good quality and adequate quantity. One can substitute other light sources for electricity or open fires for gas, and certainly one can survive without a telephone. But no one can replace water or survive without it. It is essential that our water supplies are strictly protected.

HISTORY OF WISCONSIN WATER SUPPLIES

Wisconsin people have been well served by public water supplies for more than a century. However, public water supplies in Wisconsin were relatively slow in developing. The first public water system began op-

TABLE 1. The oldest public water supplies of Wisconsin

Name	Year of installation	Source of supplies: Original	Present
1. Milwaukee	1873	R+L	L
2. Prairie du Chien	1876	G	G
3. La Crosse	1877-8	R	G
4. Kenosha	1879	G+L	L
5. Hammond	1880	G	G
6. Appleton	1882	G+R	R+L
7. Madison	1882	G	G
8. Green Bay	1883	G	G+L
9. Oshkosh	1884	G+L	L
10. Ashland	1884-5	L+I	I
11. Beloit	1885	S+O	G
12. Chippewa Falls	1885	S+O	G
13. De Pere	1885	G	G
14. Menomonie	1885	G+R	G
15. Neilsville	1885	O+R	G
16. Wausau	1885	O+R	G
17. Bayfield	1885-6	L	G
18. Stoughton	1885-6	R+G	G
19. Fond du Lac	1886	G	G
20. Superior (City)	1886-8	L+I	I

Explanation: G–ground water, I–infiltration well, L–lake, O–large open well, R–river, S–spring.

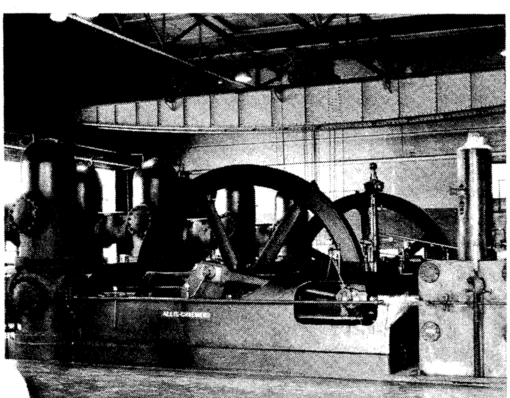

Fig. 1. The Madison Water Utility crank-and-flywheel pump, one of the few steam-driven pumps still existing in the country. It was built by Allis-Chalmers of Milwaukee, and it served Madison residents for 50 years, from 1917 to 1967, at the old Nichols pumping station on Hancock Street. (Photo: J. Brania)

erating in Boston, Massachusetts in 1652. The second system was constructed in Bethlehem, Pennsylvania in 1754. In 1873, the first public water system in Wisconsin was installed in Milwaukee. In the same decade, three other cities built public water systems: Prairie du Chien in 1876, La Crosse in 1877-78, and Kenosha in 1879. By 1886, twenty cities and villages were supplied with public systems (Table 1). Most of these communities were rapidly growing cities and villages located on large lakes or rivers.

Most of the early systems were supplied by surface water from lakes or rivers, surface water was easy to obtain—inexpensive, and at that time, of good quality. However, as the surface water became more polluted, more communities turned to ground water. The first two cities supplied by ground water from deep wells were Prairie du Chien and Madison. Classification of existing sources reveals that most communities served by public systems (about 90%) now use ground water from wells and springs. In addition, five communities have combined surface and ground-water supplies, and seven use water from surface bodies infiltrated through horizontal collectors and infiltration wells. Only seven percent of all communities served are supplied by treated lake or river water. However, these communities happen to represent a large segment of population which results in a 56:44 ratio of surface to ground-water use.

The increase in the number of public water supplies reflects the history of Wisconsin's development and the relatively uniform growth of its population. Early growth was slow from the time Wisconsin became a state in 1848 until 1884. In the early days, waterworks were unnecessary for it was easy to get satisfactory water from springs or individual wells. The first settlements were built on lakes or rivers and proximity to the surface waters also aided in fire protection.

In 1873, when the first system was built in Milwaukee the city's population was already about 80,000 and its citizens were

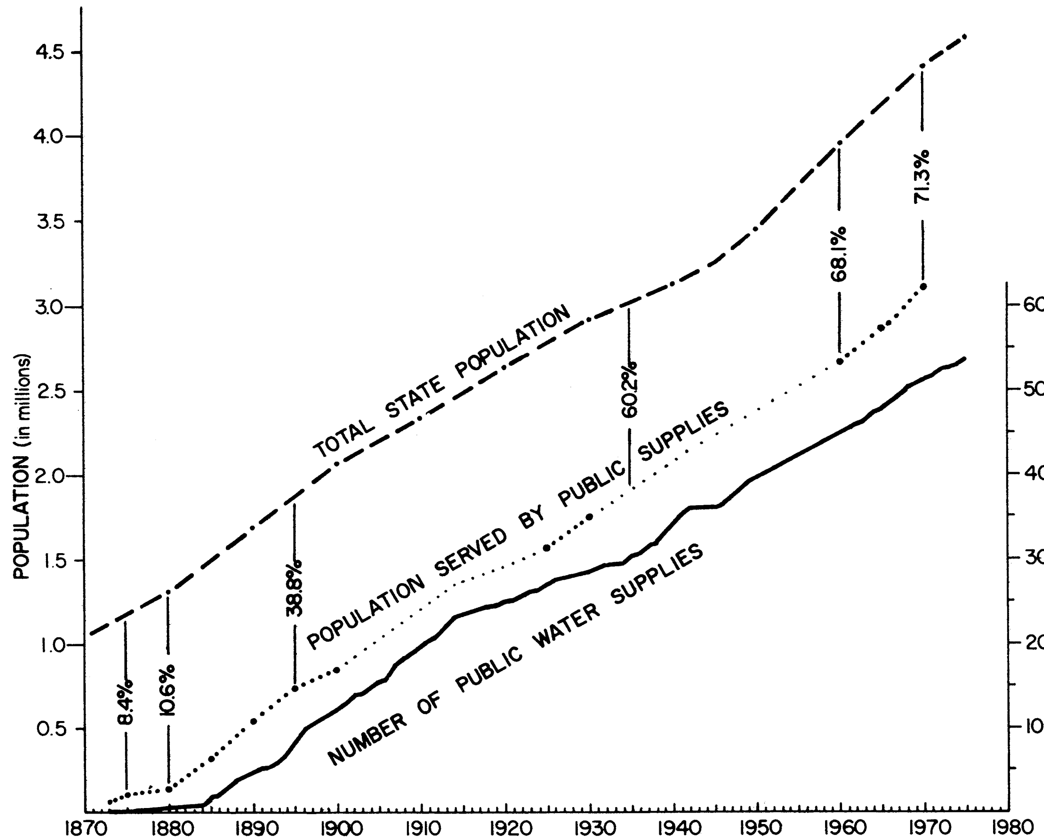

Fig. 2. Population supplied by public water systems and the number of water supplies.

dependent entirely upon domestic wells, springs, and vendors (who distributed water taken from Lake Michigan in water wagons) for water for household and industrial purposes. Fire protection for the city was primitive. Prairie du Chien, La Crosse, and Kenosha—followed the City of Milwaukee in rapid succession, forced into construction of central water systems by similar unsatisfactory water supplies.

Public demand resulted in a rapid increase of water systems from 1885 to 1891. Kirchoffer (1905) attributed this increase also to the effect of dry weather and changes in technology. Low precipitation in 1881 followed by drying up of private wells and increased danger from fire might have provided strong motivation. The introduction of the gasoline engine as a cheap source of power and the low price of iron might also have been factors. An increase in the Wisconsin population was certainly involved. The especially fast rate of growth in the years 1892-96 (over 10 new supplies each year) might also have been influenced by inexpensive material and the influx of immigrant labor, as well as by the major drought of 1894-95.

From 1897 to 1914 the number of public systems increased rather uniformly in accordance with the steady population growth. New systems averaged over seven per year. In the years 1915-1934, reflecting the economic troubles of that period culminating in the deep economic depression, only a few public supplies were built. In 1935-1942, economic recovery, stimulated new public systems at the rate of eight per year.

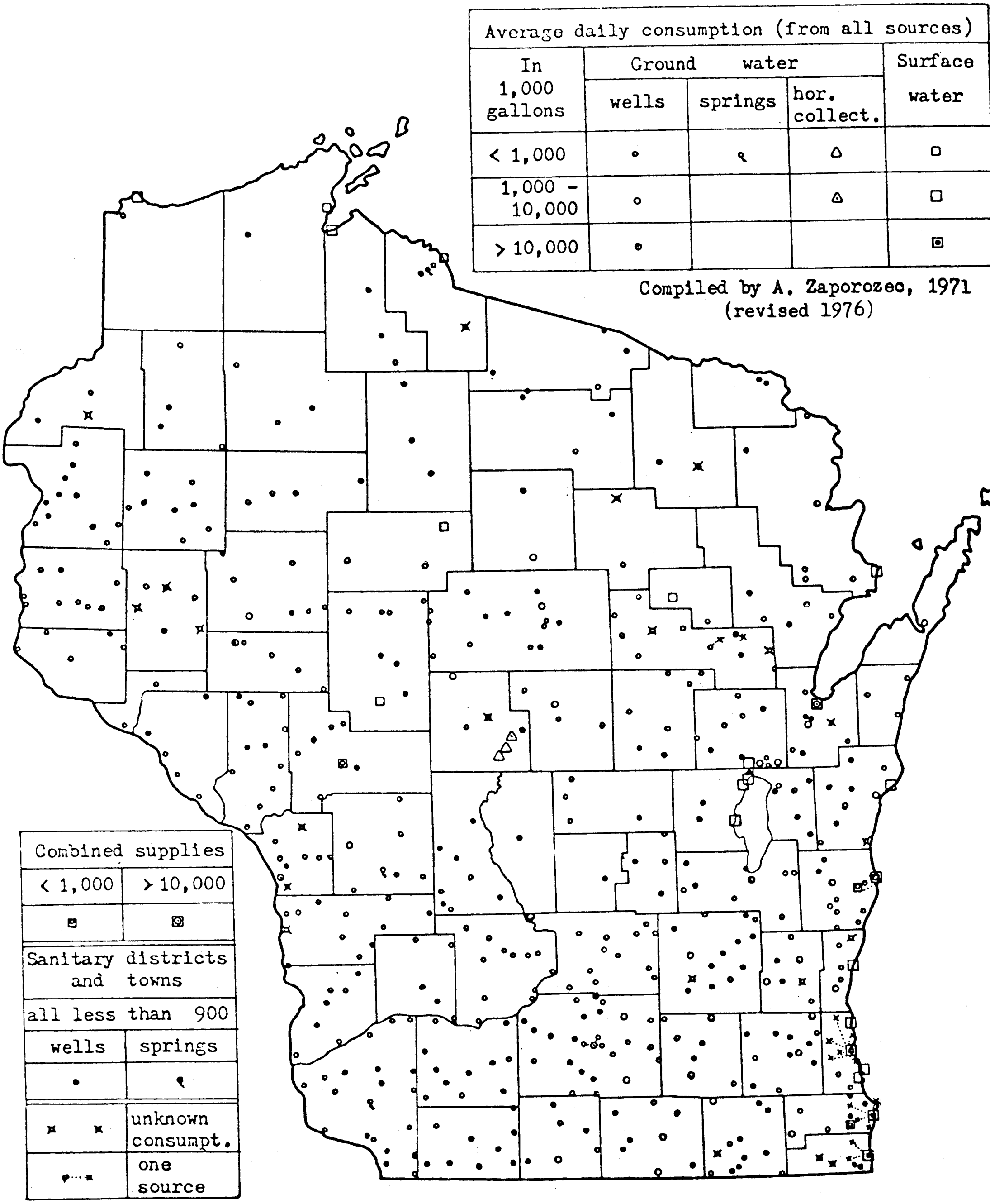

Fig. 3. Public water supplies of Wisconsin.

No public supplies were built during World War II (1943-45). The post-war economic boom and the increase in state population were probably the principal reasons for a rapid increase in public systems from 1946 to 1949, an average of over nine new supplies each year. In the 1950's to 1970's, the increase was steady, with an average of five new supplies per year from 1950-1963, and about seven new supplies per year for 1964-68. In the years 1969-1975, the rate dropped to less than five new supplies each year.

The growth in the population supplied by public systems has nearly equalled the increase in the total population of Wisconsin. At present, more than 70 percent of the population (more than 3.2 million people) is served by a public water supply system, comparing to merely eight percent in 1875, when only about 100,000 people were served. The most dramatic increase occurred in the period 1880-1895 when the percentage of the population served increased fourfold, from about ten percent to almost 40 percent of the population. The rate of increase in population served was steady between 1896 to 1935 reaching 60 percent by 1935. In the following period, 1936-1970, the percentage of population served increased only slightly to 71.3 percent. Presumably, the population supplied by public water systems will eventually level off at about 80 percent since the remaining 20 percent will be difficult or uneconomical to reach with central systems.

In 1976, there were 576 cities and villages in Wisconsin of which 461 (over 80%) have public water supplies. In addition, many towns and sanitary districts provide water for the public, bringing the total of public supplies to 533. There are also 96 private systems serving subdivisions and cooperatives. This list does not include semipublic supplies in governmental, educational, charitable and penal institutions, state parks, camps, summer resorts, etc. Many of these institutions have water supplies separate from any municipality.

Conclusion

This analysis of historical data demonstrates the importance of water supplies in Wisconsin. The need for adequate protection is evident. The State Supervision Program will certainly be an important step toward the protection and enhancement of quality in public water sources. Moreover, the cooperation of Federal and State governments in the Program, if successful, may become a model for the implementation of future legislation in such sensitive areas as consumer protection.

Acknowledgment

My sincere thanks to Mr. Robert A. Baumeister, Chief, Public Water Supply Section, Wisconsin Department of Natural Resources, and his staff for providing updated information on public supplies published in 1970 (Wis. DNR, 1970), and on the implementation of the State Surveillance Program.

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CHANGING RAIL PATTERNS IN WISCONSIN

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INTRODUCTION

The railroad industry of the United States has undergone rapid change during the 1970's. Mergers of formerly competitive railroads into combined systems have created railroads larger than ever before. On the other hand, a growing number of short lines have been established on lines abandoned by Class I railroads (railroads with annual gross revenues of $50,000,000 or more). These changes are combined with a growing number of bankruptcies and increasing federal involvement in railroad matters. The national trends are also evident in Wisconsin. This paper will examine changes taking place in railroad service in Wisconsin and will: (1) analyze the changing spatial pattern of rail service in Wisconsin, and (2) describe the current traffic density patterns on lines serving the state.

RAIL ABANDONMENTS IN WISCONSIN

Railroads in Wisconsin often mirror national trends. For example, In 1920 Wisconsin had 7,550 miles of railroad line, but in 1970 only 6,000 remained, a reduction of approximately 20 percent.[1] Concurrently, railroad mileage in the United States fell from 253,000 miles in 1920 to 206,000 miles in 1970, a reduction of 19 percent.[2] However, beginning in 1977, Wisconsin has experienced a far more rapid proportional decline in railroad mileage. Railroad service to many Wisconsin communities is likely to be lost in the next five years. The enactment of the Railroad Revitalization and Regulatory Reform Act of 1976 (4R Act), required that railroads provide states with information regarding potential abandonments. Under revised abandonment procedures growing out of the 4R Act, railroads are now required to submit maps of their lines grouped into the following categories:

Category 1—all lines which the railroad will seek to abandon within three years
Category 2—all lines under study by the railroad which may be subject to future abandonment attempts
Category 3—all lines for which an abandonment application is pending before the Interstate Commerce Commission (ICC)
Category 4—all lines that are being operated under the rail service continuation provisions of the 4R Act
Category 5—all other lines the railroad owns or operates

Service over 942 miles of rail line or 17 percent of the 1980 rail system could be lost within the next five years (Table I). Losses are expected throughout the state, but the most severe effects are centered in three areas: (1) southwestern Wisconsin, (2) the Horicon-Ripon area, and (3) from Green Bay to the Michigan border. Southwestern Wisconsin will be particularly severely affected (Fig. 1), no less than 300 miles of track are either up for abandonment or expected to be put up for abandonment. Abandonment impacts may also be severe in the Horicon-Ripon area where nearly 200 miles of line may be abandoned. Further, 100 miles of railroad line extending north from Green Bay may be abandoned. Recent efforts by the Wisconsin Department of Transportation to purchase and arrange for short line operation may permit some of these lines to remain in operation. The restructuring of the Milwaukee Road, now in the hands of a federal bankruptcy court, could result in additional abandonments.

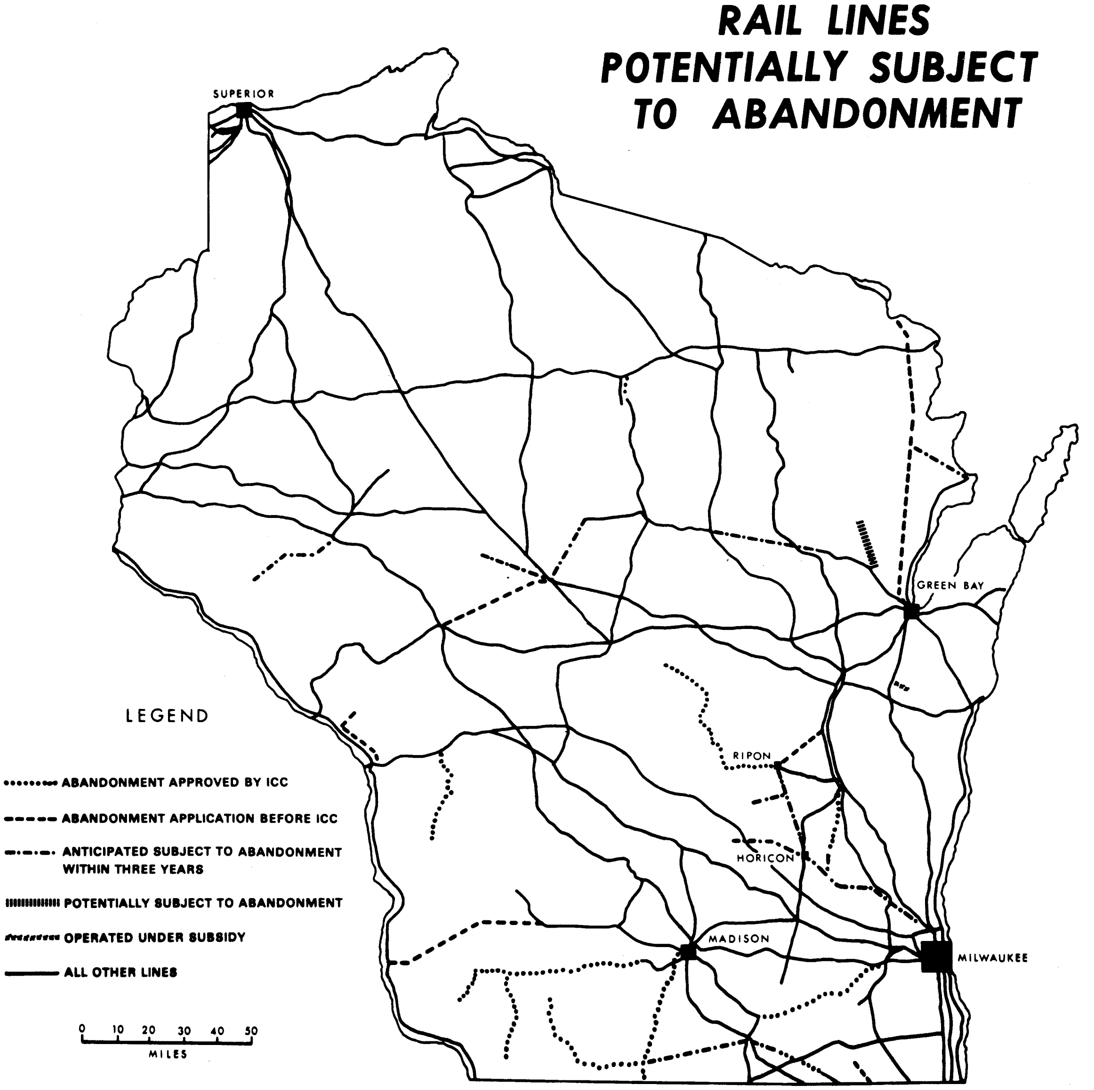

Fig. 1. Wisconsin rail lines subject to abandonment.

TABLE 1. Potential Abandonments by Wisconsin's Railroads January 1, 1980

Railroad company	*Mileage subject to abandonment by category* 1	2	3	4	*Mileage with preliminary approval for abandonment from ICC*	*Total*
Milwaukee Road	215.1	0.0	161.6	0.0	165.0	541.7
C&NW	73.2	16.2	68.8	0.0	156.6	314.8
Soo Line	26.2	0.0	0.0	0.0	0.0	26.2
All others	7.2	0.0	0.0	6.7	45.4	59.3
Total	321.7	16.2	230.4	6.7	367.0	942.0

Source: Wisconsin Department of Transportation

Conceivably, the entire Milwaukee Road mileage in Wisconsin could be subject to abandonment if that company was completely liquidated. The mileages listed in Table 1 do not reflect this remote possibility.

Railroad abandonments in Wisconsin have not been confined to recent decades, in fact, they have been occurring for 100 years. Since 1977, however, abandonments have accelerated and will probably peak within the next few years. What factors lie behind increasing rail abandonment? Early rail abandonments often resulted from depletion of resources such as minerals or forests. Abandonments in northern Wisconsin in the early decades of this century represent this type. Abandonments of short stub-ended lines represent a second type. These lines constructed to serve small farm communities have suffered from truck competition. Trucks enabled farmers to carry their agricultural products to larger markets and at the same time to purchase necessary supplies from these same markets. Loss of traffic resulted in declining revenues and subsequent application for abandonment. Many abandonments in western and central Wisconsin between 1920 and 1970 represent this type.

The number of abandonments also reflects the financial condition of the individual railroads serving Wisconsin. During the depression of the 1930's over 600 miles of rail lines were abandoned in Wisconsin.[3] Economic expansion following World War II saw the number of miles abandoned decrease as the railroads serving Wisconsin regained economic health. More recently, major segments of the American rail industry have plunged into financial difficulty and bankruptcy. The Milwaukee Road, which accounts for over 1,300 miles or approximately 25 percent of the rail mileage of the state, entered voluntary bankruptcy in December, 1977. The Chicago and Northwestern Railroad, which accounts for 40 percent of Wisconsin's rail mileage, has not been among the more profitable United States railroads in recent years. Together these two railroads account for over 90 percent of the potential rail abandonments in Wisconsin. Often railroads have been forced to reduce scheduled maintenance of their lightly used branch lines in an effort to allocate their limited resources to more productive segments of the system. Deferred maintenance, if continued over a period of years, greatly reduces efficiency by reducing operating speeds to as low as 10 miles per hour. With an operating speed of 10 miles per hour much railroad crew time is used in slow traveling between stations. As crew costs are rising, revenues are probably falling because of low speed which results in poor service and diversion of traffic to trucks. The cost of rehabilitating such a line becomes prohibitive in relation to the revenues generated. At some point in this process the railroad may petition the ICC for permission to abandon the line.

Wisconsin, unlike neighboring states to the south and west, does not originate large volumes of feed grains. The crops grown by Wisconsin farmers are converted to milk which is trucked directly to fluid milk markets or sold locally for processing into cheese. The abandonment of rural lines in Wisconsin results partly from the lack of sizable quantities of originating traffic.

In recent years, the 100 ton open or covered hopper car (used to carry coal, grain products, and fertilizers) has gained wide acceptance. These cars, with a loaded weight of 263,000 lbs. can carry 20 percent more weight than the cars they are replacing. However, they cannot be used on rail lines constructed around the turn of the century that have a light weight rail of 65 to 80 lbs. per yard. These older lines cannot compete with other rail lines capable of handling the heavier more efficient cars. Alternatives involving the use of smaller less efficient cars or partial filling of the larger cars are unattractive. Many of the lines proposed for abandonment have been those which could not handle hopper cars.

The nearly total demise of passenger service during the 1950's and 1960's, eliminated the need to maintain through lines for passenger trains. For example, a portion of the direct Milwaukee Road line between Madison and Chicago has been proposed for abandonment. This line which had passenger service as recently as April, 1971, will now cease to exist if the abandonment application is approved. As the abandonment process has accelerated, longer lines are now facing abandonment as Wisconsin railroads seek to concentrate traffic on better utilized and maintained lines.

The 4R Act provides a means whereby two railroads may meet under the auspices of the Secretary of Transportation to discuss coordinated action leading to agreements whereby one railroad agrees to abandon service to a particular market, in effect leaving all traffic to the other railroad.[4] This is considered necessary where traffic levels are insufficient to support service by two railroads. The benefits to the two railroads may be substantial, reducing costs and eliminating the need to rehabilitate track which will be abandoned. Further, provisions are made for two railroads to discuss consolidation of operations on one of two parallel main lines, thereby reducing the need to maintain duplicate trackage. Such consolidations have been discussed between the Chicago and Northwestern and Milwaukee Road railroads and one outcome could be the elimination of some parallel main line mileage.

This paper has outlined many reasons why Class I railroads are seeking to abandon lightly-used rail lines. There is, however, a growing interest by public officials and shippers in keeping these lightly used lines functioning, usually by having short line operators provide service following abandonment. Several individuals have expressed interest in establishing short line service on Wisconsin branch lines now up for abandonment. Lower operating costs coupled with federal aid for rehabilitation of the line and financial contributions from local units of government and shippers can make short line operation attractive. The alternative, providing a subsidy to a Class I railroad to operate the branch line, is considered unattractive because of high subsidy costs for a low level of service. Service on a number of Wisconsin branch lines abandoned by Class I railroads and purchased by the State of Wisconsin has been maintained by the establishment of several short line railroads.

Traffic Densities on Wisconsin Railroads

Until recently density maps of rail traffic were not generally available to the public. However, with increasing governmental involvement in railroad matters at both federal and state levels, this information is now available in state and federal reports.[5] A simplified map (Fig. 2) depicts the wide variation in traffic densities on Wisconsin rail lines. The gross tonnages include the weight of loaded and empty cars, locomotives, and cabooses passing over each mile of railroad.[6] The actual weight of the cargo is estimated to be slightly less than one-half the gross tonnage.[7] It is evident that most

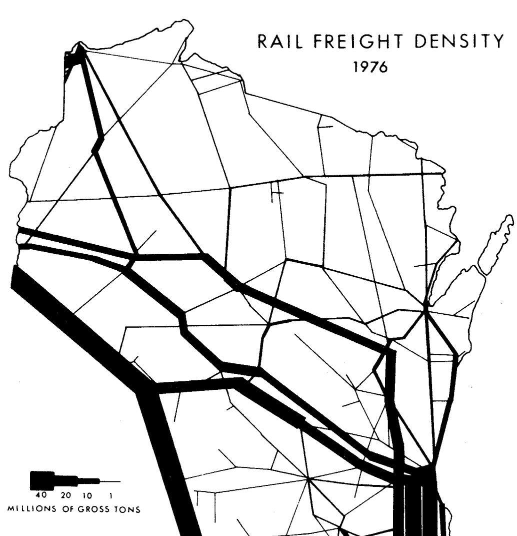

Fig. 2. Wisconsin rail freight density in 1976.

TABLE 2. Railroad Company Mileage by Density Group (1976)

Railroad	0-0.9	*Millions of gross tons per mile* 1.0-4.9	5.0-9.9	10.0-19.9	20 & Over	*Total miles*
C&NW	807	818	420	240	48	2333
Milw. Road	638	395	124	89	139	1385
Soo Line	122	816	75	293	0	1306
All Other	162	246	29	10	236	683
Total	1729	2275	648	632	423	5707
Percentage	30.3%	39.9%	11.4%	11.1%	7.4%	100.0%

Source: Wisconsin Railroad Plan, December, 1979 p. V-21

rail lines in the state carry only light traffic. Seventy percent of Wisconsin's rail mileage carries branch line densities of less than five million gross tons per year (Table 2).[8] Nationally, 49 percent of United States rail lines carry less than five million gross tons.[9]

Wisconsin lines bearing the heaviest traffic connect Chicago with Minneapolis-St. Paul. Much of the traffic carried by these lines is moving through the state rather than originating or terminating there. The highest density line, that of the Burlington Northern paralleling the Mississippi River, carries little traffic originating or terminating in Wisconsin. Instead, it carries low sulfur coal and lumber products east and manufactured products west. The Milwaukee Road, Chicago and Northwestern, and Soo Line routes between Chicago and the Twin Cities also carry heavy volumes of through traffic. On the other hand, much of the traffic moving south from Green Bay and other Fox Valley cities consists of paper and related products manufactured in these cities. Considerable tonnages of raw materials and steel products move into Milwaukee where they are converted into automobile frames, beer, and other manufactured products, then shipped south through Chicago for distribution throughout the United States. Large tonnages of iron ore, low sulfur coal, and grains move by rail to the port of Superior for shipment on the Great Lakes. These tonnages move only a few miles in Wisconsin. The majority of the remaining lines in Wisconsin carry only light traffic densities, a fact reflected in the growing number of petitions for abandonment.

CONCLUSION

Wisconsin railroads face an uncertain future. Recent growth in traffic has been confined to the more heavily used routes. Lightly used branch lines are increasingly being proposed for abandonment. Whether merger of the Milwaukee Road and the Chicago and Northwestern with stronger railroads would materially change the existing situation is difficult to assess. It is hoped that the railroads serving Wisconsin will regain their vitality so that they may again contribute to Wisconsin's economic well being.

NOTES

[1] Wisconsin Department of Transportation, Wisconsin Railroad Plan. August 1, 1977, p. V-2.

[2] Association of American Railroads, Yearbook of Railroad Facts, 1978 ed., p. 46.

[3] Wisconsin Railroad Plan, p. V-2.

[4] United States Department of Transportation, News Release, June 15, 1978.

[5] Wisconsin Railroad Plan, p. V-24, and United States Department of Transportation, United States Transportation Zone Maps, 1975.

[6] Wisconsin Railroad Plan, p. V-22.

[7] Ibid., p. V-22.

[8] Ibid., p. V-23.

[9] United States Department of Transportation, Final Standards, Classification, and Designation of Lines of Class I Railroads in the United States, Vol. 1, January 19, 1977.

FIELD IDENTIFICATION OF *PEROMYSCUS LEUCOPUS* AND *P. MANICULATUS* WITH DISCRIMINANT ANALYSIS

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Abstract

Discriminant analysis produced non-overlapping groups of scores for morphologically similar individuals of *Peromyscus maniculatus bairdi* and *P. leucopus noveboracensis* from southern Wisconsin. This analysis was based on standard external measurements and can be used in field studies requiring identification of these mice.

Biologists have been hampered in studies of closely related species of *Peromyscus* because of difficulty in the identification of individuals with intermediate characteristics. This difficulty has been cited by Hall and Kelson (1959), Jackson (1961), and Findley, et al. (1975) and appears to be a widespread problem in North America (Hooper, 1968). Many keys to the species are based on skull characteristics (Hall and Kelson, 1959; Findley, 1975, Lechleitner, 1969) although external attributes may be included.

Experiments with *Peromyscus* frequently require identification of species based on intact specimens (McNab and Morrison, 1963). However, criteria for separating southern Wisconsin, *Peromyscus* species on the basis of external characteristics, do not always provide satisfactory identifications (Fig. 1). This paper demonstrates the use of discriminant analysis for field identification of *Peromyscus maniculatus bairdi* (*P. m. b.*) and *P. leucopus noveboracensis* (*P. l. n.*). Individuals of these species are difficult to tell apart in areas of sympatry (Hall and Kelson, 1959:628; Jackson, 1961:213) yet the species are frequently used in ecological studies (Miller, 1975; Master, 1977). Although morphologically similar, these species show no evidence of inter-fertility (Dice, 1933). Habitats are partitioned by these species when they co-occur: *P. l. n.* occupies deciduous forests but can survive in fields (Stromberg, 1979), *P. m. b.* selects old fields or prairies (Wecker, 1963; Master, 1977) and cannot survive as well in forests (Stromberg, 1979).

Four field measurements (total length, tail length, hind foot length, and ear length) were made on each animal following Hall (1962). The same four measurements were made on museum specimens at the Zoology Museum, University of Wisconsin, Madison. Data on tags were frequently incomplete so all skins were re-measured following Hall (1962). The number of museum specimens examined of *P. l. n.* and *P. m. b.* respectively are given following the Wisconsin county name: Clark 1,1; Dane 4,15; Dodge 9,16; Door 1,0; Jackson 3,0; Jefferson 1,1; Kewaunee 0,1; Langlade 1,0; Manitowoc 2,0; Marathon 0,1; Marinette 5,0; Milwaukee 4,0; Monroe 1,0; Oneida 1,0; Racine 2,0; Rock 2,4; Sauk 1,0; Shawano 1,0; Sheboygan 1,0; Waukesha 6,1; Waupaca 5,6. A few specimens from other areas were available. These include, Long Island, New York 1,0; Hyattsville, Mo. 1,0; Carthage, Mo. 0,2.

Mice were trapped from September 1976 to Septetmber 1977 at two locations in Sauk County, Wisconsin. Specimens of *P. l. n.* were measured in the Potter Preserve (T-

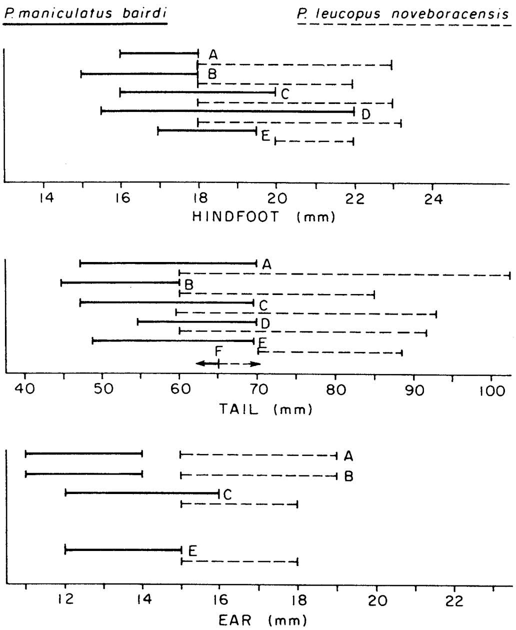

Fig. 1. Range of hindfoot, tail and ear lengths for *P. maniculatus bairdi* and *P. leucopus novaboracensis*. Sources: A. Peterson, 19666; B. Hoffmeister, Mohr, 1957; C. Burt, 1946;; D. Hamilton, 1943; E. Jackson, 1961; F. Hall and Kelson, 1959.

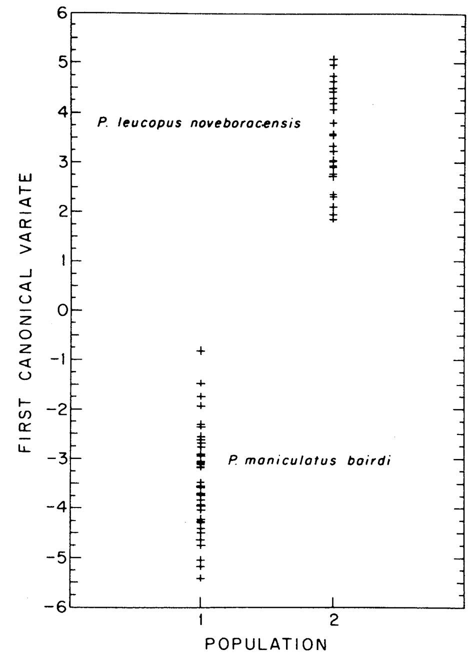

Fig. 2. Discriminant scores for individual *Peromyscus* measured in the field in Sauk Co., Wisconsin.

11N, R-7E, S-2) in oak-hickory forest. Specimens of *P. m. b.* were measured in Peetz's Prairie and Schluckebier Prairie (T-9N, R-6E, S-4) a dry undisturbed prairie dominated by *Andropogon scoparius.*

Discriminant analysis (Seal, 1964; Rao, 1952) produces a linear function (scores), based on the original variables:

$$y = \sum_{i=1}^{4} a_i x_i$$

(where the x_i's are the four characters {total, tail, hind foot, ear} and the a_i's are four coefficients) which maximize the F-ratio of variance among groups to pooled variance within groups allowing calculation of the position of a point for each specimen along a single synthetic axis. Once this linear function is determined for a reference set of animals, future field identification can be done using portable pocket calculator to calculate scores for new specimens.

A constant was added to the function so that the values center on zero. This does not affect the properties of the discriminant function (Seal, 1964). I used the program CANON (Kowal, et al., 1976) on a Univac 1110 computer.

The validity of a discriminant function must be evaluated (Morrison, 1969). This was done by calculating a discriminant function based on field measurements and then using the resultant coefficients to re-classify reference museum specimens. The museum specimens chosen were only those Wisconsin specimens which had been previously classified to species by H. H. T. Jackson, F. J. W. Schmidt or W. E. Snyder. The percentage of correctly classified museum specimens reflects the validity of the discriminant function based on field characteristics. Voucher specimens identified with this discriminant function are available in the University of Wisconsin Zoology Museum.

TABLE 1. Coefficients of the discriminant function based on field measurements. These coefficients depend on the units of measurement and are for use on raw data. Standardized coefficients are independent of the units of measurement and allow comparisons of the absolute value of the coefficients to determine relative importance of each character in discrimination. Means (mm) and standard deviations (S.D.) are included. Double asterisk indicates significant difference ($p < 0.01$) between field and museum measurements. Field sample size for *Peromyscus leucopus noveboracensis* (P.l.n.) is 41; for *P. maniculatus bairdi* (P.m.b.) is 28. Museum sample sizes (respectively) are 53 and 48.

Character	*Coefficients*	*Standardized Coefficients*	*Mean* *P.l.n*	*Mean* *P.m.b.*	*S.D.* *P.l.n.*	*S.D.* *P.m.b.*
(Field)						
1. Total	—0.01841	.28225	168.70	137.46	9.07	7.73
2. Tail	—0.05168	.49557	77.90**	58.85	5.52	4.84
3. Hindfoot	—0.84200	.99905	20.24	16.96	0.592	0.727
4. Ear	—1.12028	1.00000	15.05	12.82**	0.552	0.390
Constant	37.62291	37.62291	—	—	—	—
(Museum)						
1. Total	0.00013	—.00174	167.77	138.50	11.561	9.335
2. Tail	—0.02021	.14996	74.72**	57.25	5.879	5.601
3. Hindfoot	—1.07210	.76205	20.13	17.08	0.556	0.539
4. Ear	—1.84249	1.00000	14.91	11.94**	0.295	0.522
Constant	45.99161	45.99161	—	—	—	—

RESULTS

There is no overlap in discriminant scores between the two species for mice measured in the field (Fig. 2). The Mahalanobis' distance (in standard deviation units) between means of each group is 6.8. Males and females were evenly scattered over the range of scores for each species, hence data were combined for presentation. Coefficients and data parameters for field measurements (Table 1) indicate that the ear, and hind foot were most useful in discrimination. Again for the mice measured in the museum, ear and hind foot were the most useful characters in discriminating *P. l. n.* and *P. m. b.* (Table 1). Most means for museum measurements are not significantly different from field measurements ($p > 0.05$, t-test). However, in the field, ear length of *P. m. b.* and tail length of *P. l. n.* are longer ($p < 0.01$, t-test).

The field discriminant function was used to score museum specimens to evaluate the function's validity. There was no overlap in the scores and no individuals were misclassified. Mahalanobis' distance between the means of each group is 7.3. This implies a probability of less than 0.01 of mis-classification when using the discriminant function for mice measured in the field (Fig. 3).

DISCUSSION

The agreement of museum and field measurement is generally good. When differences occur, they suggest shrinkage, which reduces comparable field values by a small factor. This factor is likely constant for all four characters; each depends on shrinkage of similar skin.

Because the field and museum data are so similar, the fact that the field discriminant function performed well (100% correct) on museum specimens seems reasonable. Moreover, a constant shrinkage factor essentially multiplies the field data by a constant, which does not change the relative position of discriminant scores.

Discriminant analysis assumes an *a priori* grouping of individuals (Seal, 1964). In this case, there was no overlap in field hind foot measurements. Individuals with hind feet of 19 mm or larger were considered *P. l. n.* and those with hind feet 18 mm or shorter were tentatively classified as *P. m. b.*

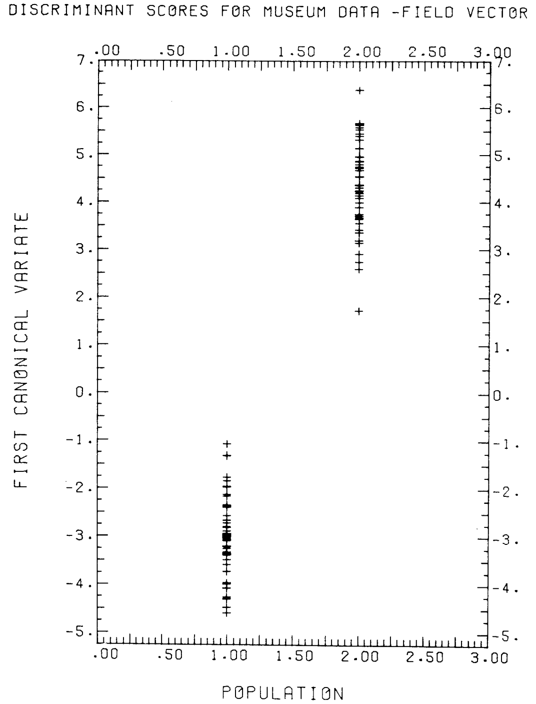

Fig. 3. Discriminant scores for previously identified (reference) museum specimens using the discriminant function derived from field measurements of intact individuals in Sauk C., Wisconsin. Population one is *Peromyscus leucopus noveboracensis* and population two is *P. maniculatus bairdi.*

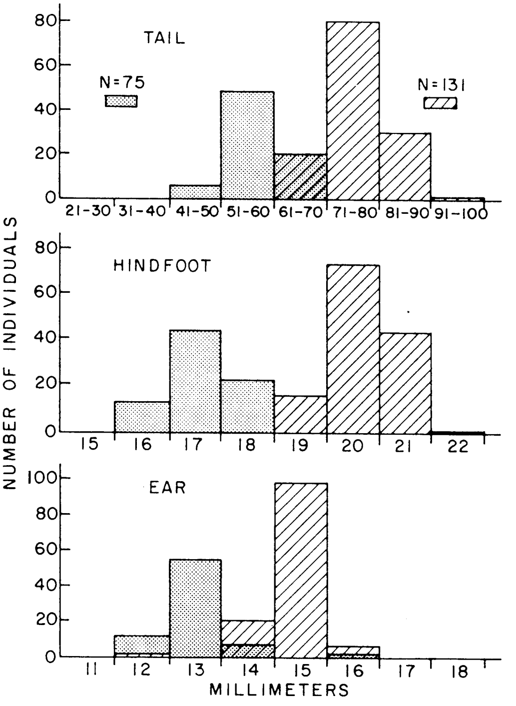

Fig. 4. Data from individual mice measured in the field were plotted as shaded (left) if hindfoot was $\leq$ 18 mm, or slashed (right) if handfoot was $\geq$ 19 mm. Additional mice from Dane, Columbia, and Rock Co., Wisconsin are included. Smaller individuals were tentatively identified as *P. maniculatus bairdi* based on non-overlap of hindfoot measurements. Larger individuals were tentatively classified as *P. leucopus noveboracensis* for later discriminant function calculation.

(Fig. 4). Although this one character showed an apparent consistent difference, other measurements for most individuals were not useful in discrimination. Field data for tail and total length showed extensive overlap. I have used the field function on intermediate, unidentified specimens in the museum (U.W.-Madison) and their scores fall clearly within one of the distinct groups determined by the above verification process.

Use of a discriminant function accomplished several things in an objective manner. First, it demonstrates that two groups may be distinguished on the basis of external characters (Fig. 2) although previous workers implied that separation on field data was difficult or impossible (Peterson, 1966); Hoffmeister and Mohr, 1957; Burt, 1946; Hamilton, 1943; Jackson, 1961; Hall and Kelson, 1959). Discriminant analysis with large sample sizes will not produce distinct groups if indeed the *a priori* grouping was meaningless (Kowal, et al., 1976). Second, many characters are considered simultaneously in the classification process so that mis-classification resulting from the use of a single spuriously errant character is avoided. Third, intact individuals can be classified with reasonable confidence. Thus, the use of this discriminant function in identification of *Peromyscus* with field characters should offer behaviorists, ecologists and physiologists a dependable alternative to use of cranial measurements.

This example clarifies the distinction between *P. maniculatus bairdi* and *P. leucopus noveboracensis* in southern Wisconsin)Jackson, 1961). Considerable variation exists in these two species, and this discriminant function must be used only in southern Wisconsin. The function is probably not valid over the entire range of overlap between the two species. For instance, the hindfoot pattern allowing initial *a priori* groupings of these mice does not hold true in Minnesota (E. C. Birney, pers. comm., 1979). To help discriminate between these species over their entire range of sympatry, canonical analysis, an extension of discriminant analysis can be used. Principal component analysis may be a useful way to establish *a priori* grouping (Seal, 1964) of local populations. This may also be useful in the western U.S. where many morphologically similar species of *Peromyscus* occur together (see Findley, et al., 1975; Hall and Kelson, 1959).

These two *Peromyscus* species in Minnesota are apparently externally more similar than in southern Wisconsin (E. C. Birney, pers. comm., 1979). Horner (1954) found tail length to be related to climbing ability: long tails meant better climbing in forest habitats. Dice (1940) suggested the general correlation of longer tail length and hind foot length with increased arboreal habit in relation to the shorter forms in prairie habitats. Miller (1975) found a transition in habitat utilization by *P. m. b.;* from northern Minnesota to Iowa and southern Michigan, this species shows a gradual increase in field versus forest habitat use. Iverson, et al. (1976) observed *P. m. b.* from northwestern Minnesota in aspen and riparian habitats wherever *P. l. n.* was absent. Perhaps the morphological similarity between these species reflects convergence in their habitat use in Minnesota. This possible character displacement (Dunham, et al., 1979) could be studied by comparing the allopatric forest populations of northwestern Minnesota to sympatric populations in southern Wisconsin or Michigan. Greater differences in habitat use and in morphology may be evident in southern Wisconsin and Michigan where these populations are thought to have co-occurred for a relatively long time since the glacial retreat (Miller, 1975).

Acknowledgments

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THE NORTHERNMOST STATION FOR *ASPLENIUM PINNATIFIDUM*

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Abstract

Lobed spleenwort (*Asplenium pinnatifidum*) is reported from 148 counties in the Appalachian Mountains and 49 counties in east-central United States. The northernmost station of this fern is found on Pinnacle Rock in Iowa County, Wisconsin. The markedly discontinuous distribution of the lobed spleenwort outside of the Appalachians is largely determined by its requirement for an acidic substrate and for a rock cliff habitat.

Although long considered one of the Appalachian Aspleniums,[1,2] the lobed spleenwort (*Asplenium pinnatifidum*) has been reported from 49 counties in east-central United States (Fig. 1), ranging northwest to Wisconsin and southwestward to Oklahoma. The record of this fern in each of the 197 counties (Table 1 and Table 2) is based upon collections reported in a publication or established by correspondence with herbarium curators and pteridologists. Records were discounted if a correction had been published,[3] or if there was evidence of confusion in identification or uncertainty of the collection site.

The markedly discontinous distribution of *Asplenium pinnatifidum* outside of the Appalachian Mountains is largely determined by its requirement for an acidic or sub-acidic substrate and for the exacting microclimate associated with rock cliffs. In all of the 19 states where the fern has been reported, it occurs in restricted localities growing usually on sandstone, but occasionally on gneiss,[4,5,6] or granitic rock.[7,8]

The northernmost station for *Asplenium pinnatifidum* is on Pinnacle Rock in the Town of Arena, Iowa County, Wisconsin. Discovered by Hugh Iltis in 1958,[9] the colony has numbered about 80 plants over the last 21 years. The fern grows in small crevices in St. Peter sandstone principally on the east and northeast face of the rock, although deeper sheltered crevices on the south support a few plants. It is not associated with any other fern or higher plant in these crevices.

A second station in Wisconsin is located on Pompey's Pillar in the Town of Highland in Iowa County. Discovered by William Tans in 1969,[9] this colony, also in crevices of the St. Peter sandstone, has numbered over 50 plants for the last 10 years. The largest number of ferns are on the south face of the pillar, but a few grow on the north face.

The third and fourth stations, one on Cave Bluff in the Town of Brigham, and the other on Iron Rock in the Town of Arena, were discovered by the authors in 1970.[9] More than 100 plants have maintained their numbers over the past 9 years on Cave Bluff and several bluffs that face it across a narrow valley. These cliffs of St. Peter sandstone have a verticle exposure of 50 to 80 feet. On Iron Rock, 15 ferns make up the colony growing on the east and north face. The St. Peter sandstone of this outcrop has weathered more deeply than that of the other sites and is colored with iron pigment. However, none of the crevices occupied by the fern on this rock, or those of the other three sites allow accumulation of leaf litter, or provide a site for other plants.

The two Arena stations and the Brigham station are within 2 miles of each other, and

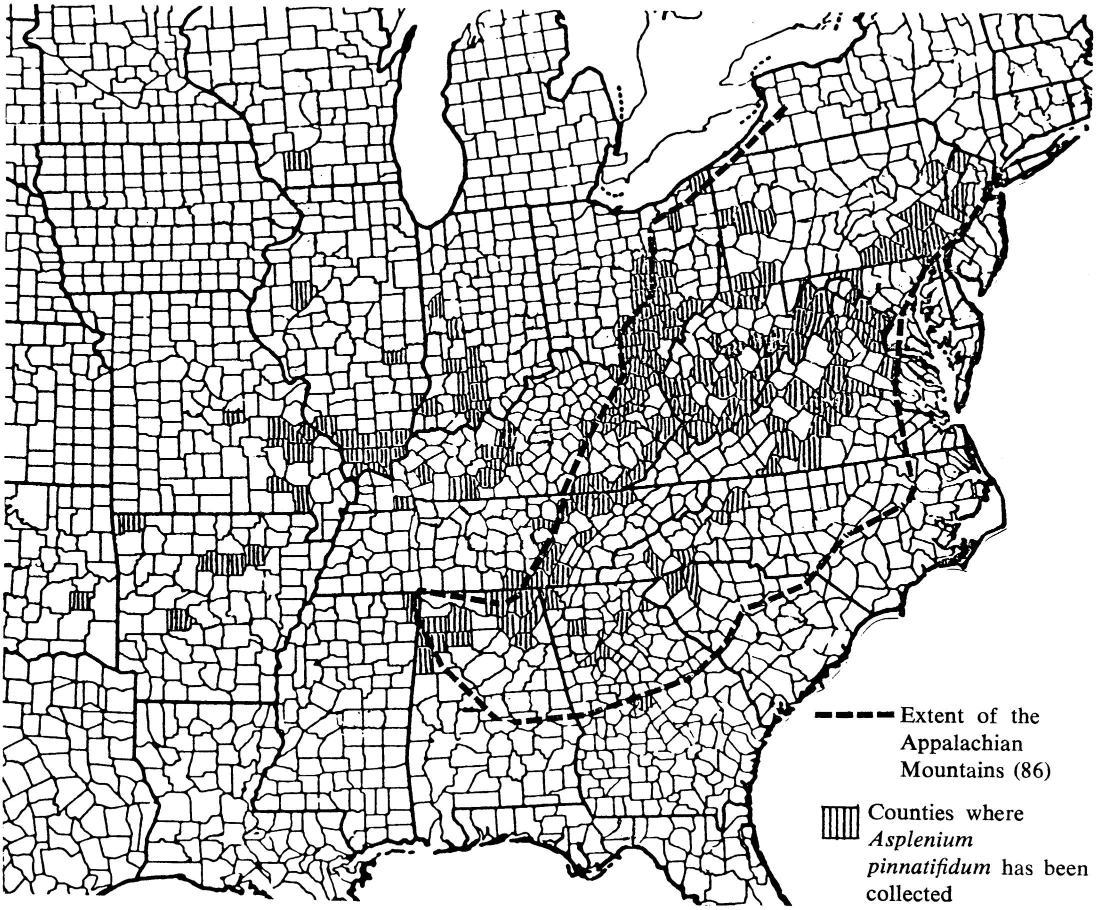

Fig. 1. County distribution of *Asplenium pinnatifidum* in the United States in relation to the Appalachian Mountains.

TABLE 1. Distribution of *Asplenium pinnatifidum* by counties in east-central United States

State	*Counties*
Northern Arkansas	Benton (11,12,13)
	Cleburne, Van Buren (12)
	Garland, Independence (11,12)
Illinois	Cumberland, Fulton, Massac (14, 15)
	Gallatin, Hardin, Jackson, Johnson, Pope, Saline, Union, Wabash, Williamson (15,16)
	Pulaski (17)
	Randolph (17,18,19)
Indiana	Crawford, Martin (20,21,22,23,24)
	Dubois, Gibson (23)
	Fountain (20,21,22,25)
	Greene, Orange, Perry (21,22)
	Lawrence (20,21,22)
	Monroe (2,23)
	Putnam (22)
Western Kentucky	Caldwell, Grayson, Hart, Logan, Todd (26)
	Calloway, Edmonson (26,27)
	Hardin (26,28)
	Warren (26,27,29,30,31)
Southeastern Missouri	Butler, Carter, Iron, Madison, Maries, Saint Francois, Sainte Genevieve, Washington (32)
Eastern Oklahoma	Latimer (25,33,34,35,36)
Southwestern Wisconsin	Iowa (9,37)

TABLE 2. Distribution of *Asplenium pinnatifidum* by counties in the Appalachian Highlands

State	*Counties*
Northern Alabama	DeKalb (38,39) Etowah (38,40) Franklin, Lamar, Lawrence, Madison, Marion (41) Jackson (38,41) Marshall (38) Winston (42)
Northern Georgia	Bartow, DeKalb (5,43,44) Bibb (25,43,45) Dade (5,8,39,43,46) Fulton (5,43) Hall (43,47) Stephens (6,8,43) Twiggs (8, 43) Walker (5,8)
Eastern Kentucky	Bell, Boyd, Carter, Elliott, Floyd, Greenup, Madison, McCreary, Morgan, Rockcastle, Rowan, Whitley (26,27) Breathitt, Lee, Menifee, Wolfe (48) Harlan, Letcher, Lewis, Pike (26) Powell (26,27,48)
Northern Maryland	Cecil (49,50,51) Washington (52)
Northeastern Mississippi	Tishomingo (53,54,55)
Northern New Jersey	Hunterdon, Sussex (56,57)
Western North Carolina	Caldwell, Wilkes (58,59) Henderson, Jackson (58,59,60)
Eastern Ohio	Ashtabula (61) Athens, Coshocton, Fairfield, Hocking (61,62) Jackson, Pike (62,63) Knox, Summit (64) Lawrence, Meigs, Muskingum, Perry, Ross, Scioto, Vinton, Washington (62) Licking (2,62)
Pennsylvania	Adams, Chester (65,66) Armstrong, Greene (65,66,67) Berks (65,66,67,68) Bucks (66,69) Butler, Lawrence (65,67) Delaware (70) Fayette (65,66,67,70,71) Lancaster (40,65,66,67,70) Monroe (67) Philadelphia (4,25,65,66,67,70) York (2,40,65,66,67,70)
Western South Carolina	Greenville (58,59,72) Pickens (58,59,72,73)
Eastern Tennessee	Bledsoe, Campbell, Fentress, Franklin, Hamilton, Putnam, Roane, Scot, Sequatchie, Van Buren (74,75) Claiborne (74) Marion (74,75,76)
Virginia	Albemarle, Alleghany, Amherst, Appomattox, Buchanan, Buckingham, Caroline, Fluvanna, Franklin, Goochland, Greene, Nelson, Page (77) Campbell, Fairfax, Giles, Loudoun, Patrick, Pittsylvania, Rockbridge, Stafford (77,78) Clarke (40,79) Fauquier, Prince William (78) Roanoke (7,77,78) Shenandoah (2)
West Virginia	Baxton, Kanawha, Lincoln, Logan, Marion, Mercer, Mingo, Nicholas (80) Calhoun, Fayette, Grant, Hampshire, Mineral, Monongalia, Pendleton, Pocahontas, Randolph, Summers, Wayne, Wetzel, Wyoming (80,81) Greenbrier, Monroe (80,81,82) Hardy (2,80,81) Jefferson (80,81,83,84,85) McDowell (81) Upshur (40,80,81)

lie 22 miles east of the Highland station (Fig. 2). Over 15 similar sandstone bluffs and pinnacles within this area of the Wisconsin driftless region have been examined without finding a single plant. There is no reason to believe that collectors have extirpated this fern in Wisconsin, as they have not known of its presence. Nor is there any

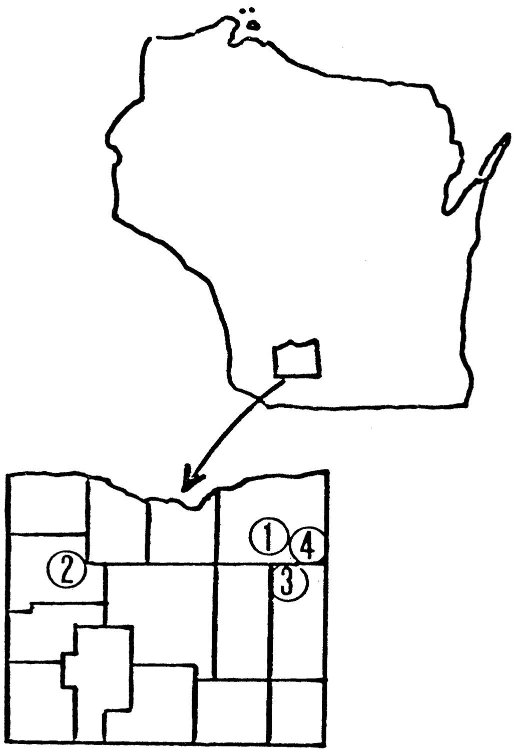

Fig. 2. Four stations of *Asplenium pinnatifidum* in Iowa County. 1. Pinnacle Rock 2. Pompey's Pillar 3. Cave Bluff 4. Iron Rock.

obvious reason why the fern should have disappeared from apparently suitable sandstone bluffs within southwestern Wisconsin, or should have failed to colonize them.

Wisconsin colonies of the fern appear to have been unaffected by fluctuations in the weather during the 21 years of observation in which some of the driest and wettest years on record have occurred in Iowa County.[10] For most of the past 100 years, the land around the bluffs has been periodically burned and continuously pastured. This is now changing as the present owners of all 4 sites have allowed afforestation to take place, a practice which creates shade where it never existed and modifies the force and flow of the wind.

Periodic inventory of the Wisconsin population of the lobed spleenwort should reveal any biologic response such as reduction in numbers, altered growth, or appearance of disease that may result from environmental change. By comparing the relative persistence of the fern at the four sites, it may be possible to develop a management strategy that will insure the survival of this rare fern.

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SENECELLA CALANOIDES JUDAY (CALANOIDA, COPEPODA), *MESOCYCLOPS LEUKARTI* CLAUS (CYCLOPOIDA, COPEPODA), AND *DAPHNIA LAEVIS* BIRGE (CLADOCERA) IN INLAND WISCONSIN LAKES

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Whitefish Lake (Sawyer County, Wisconsin) was found to support a population of *Senecella calanoides* Juday. Whitefish Lake is a softwater drainage lake, maximum depth of 31 m and an area of 371 ha. The littoral zone is unsorted sand and gravel with muck bottom in the deeper areas; aquatic vegetation is scarce. Cisco (*Coregonus artedi*) and whitefish (*Coregonus clupeaformis*) are common. Dissolved oxygen was present (0.7 mg/L) at the bottom in late August and secchi disc visibility ranged from 3-4 m.

Senecella calanoides was collected in August and November 1978 by vertical tows using a no. 10 mesh (120 u pore size) conical net (15 cm mouth). On these dates *S. calanoides* was uncommon and only fifth copepodid (CV) males and females were found. *Senecella* is known to be univoltine with long generation times, usually shedding eggs during the winter (Carter 1969; Selgeby 1975). *S. calanoides* is distinguished by its large size (2.4-2.9 mm), the male right first antenna not being geniculate and females lacking fifth legs. The male fifth copepodid (CV) stage can be identified on the basis of its large size and the structure of the fifth legs (Wilson 1959). Other species found in Whitefish Lake were *Skistodiaptomus oregonensis, Leptodiaptomus minutus, L. sicilis, Acanthocyclops vernalis, Tropocyclops prasinus, Cyclops bicuspidatus thomasi, Daphnia catawba, D. retrocurva, Sida crystallina*, and *Holopedium gibberum*.

Much attention has been given to "glacial relicts" *Mysis, Limnocalanus, Pontoporeia* and *Senecella* in the Great Lakes (Carter 1969; Torke 1974; Selgeby 1975; Morgan and Beeton 1978); investigations in Ontario and eastern North America have examined occurrence and glacial dispersal of the deepwater zooplankton communities in inland lakes (Martin and Chapman 1965; Hamilton 1971; Patalas 1971; Dadswell 1974). Dadswell (1974) demonstrated a relationship between the distribution of these deepwater communities and the extent of glaciation in North America. His observations suggest that the deepwater plankton community invaded inland fresh waters either by marine flooding or through water ponded in front of advancing ice. The latter mechanism seems probable in Wisconsin.

Reports of *Mysis relicta* Lovén in four inland Wisconsin lakes and *Limnocalanus macrurus* Sars in one (Marsh 1893; Juday 1904; Juday and Birge 1927; Couey 1934; Mcknight 1976) support Dadswell's conclusions and match the extent of Wisconsin glaciation. *Senecella* has not been recorded previously in an inland Wisconsin lake. Recent collections from Geneva Lake (Walworth County), where *Limnocalanus* had been reported (Juday 1904), have failed to produce specimens of *L. macrurus* or *S. calanoides*. Gannon, et al. (1978) report *S. calanoides* in one inland Michigan lake.

These deepwater species may be present in other lakes within the glacial boundaries but sampling has been limited. A conical plankton net with a large mesh size (No. 6) and large mouth (30 cm), or a trawl would be most productive in sampling for these deepwater species; net avoidance and low density may be problems.

Mesocyclops leuckarti Claus and *Daphnia laevis* Birge were collected from Lilly

Lake (Kenosha County, Wisconsin). Because it is small and shallow (maximum depth of 2 m and 32 ha in area), Lilly Lake experiences problems with aquatic weed growth and winterkill. It has a fish population composed primarily of bass and panfish. The zooplankton community reflects the habitat and is comprised of *Bosmina longirostris, Eubosmina coregoni, Diaphanosoma leuchtenbergianum, Daphnia laevis, Ceriodaphnia lacustris, C. reticulata, C. quadrangula, Skistodiaptomus oregonensis, Epischura lacustris, Mesocyclops edax, M. leuckarti, Tropocyclops prasinus, Macrocyclops albidus,* and numerous chydorids and ostracods.

Adult *M. leuckarti* were collected in small numbers in 1978. *M. leuckarti* was distinguished from *M. edax* on the basis of the hyaline membrane of the terminal segment of the first antennae, lack of hairs on the inner margin of the caudal rami and structure of the fourth and fifth legs (Yeatman, 1959). Immature individuals were indistinguishable from immature *M. edax* with which it occurs.

In examining collections from 190 inland Wisconsin lakes, Torke (1979) did not find *M. leuckarti,* nor has its presence in Wisconsin waters been reported elsewhere. Yeatman (1959) describes this species as being widely distributed in North America but scarce and suggests that many individuals recorded as *M. leuckarti* are actually *M. edax.* In Canada, Smith and Fernando (1977) found *M. leuckarti* to inhabit diverse habitats, from bogs and marshes to large clear lakes. This species has been reported from British Columbia, Quebec and Saskatchewan (Willey 1925; Carl 1940; Moore 1952).

In 1978, adult *D. laevis* were collected in samples from Lilly Lake, but were always rare. Males and females closely resembled the specimen described by Brooks (1957, p. 120; plate 21 E,F,K,L) from a temporary pool in New Haven, Connecticut. Torke (1979) did not find *D. laevis* in his original work on 190 Wisconsin lakes, however, it was later found in Little Mud L., Fond du Lac Co., Camp L., Bayfield Co. and Rush L., Douglas Co. (Torke, pers. comm.). Brooks (1957) describes *D. laevis* as a species of the southern United States, but notes it has been found as far north as southern Michigan, Minnesota and New England.

Brooks also considers *D. laevis* to be parent stock of the pelagic *Daphnia dubia.* Specimens described by Brooks (1957) were collected in temporary ponds and pools, habitats similar to Lilly Lake.

This work, that of Torke and of the Wisconsin DNR Bureau of Research, continues the early studies of Birge, Juday, Marsh and others in an attempt to more fully understand and document the distribution and ecology of Wisconsin zooplankton.

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