Transactions of the Wisconsin Academy of Sciences, Arts and Letters. volume 73 1985

Madison, Wis.: Wisconsin Academy of Sciences, Arts and Letters, 1985

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TRANSACTIONS
OF THE
WISCONSIN ACADEMY
OF SCIENCES, ARTS
AND LETTERS

Volume 73, 1985

Funds for this issue of the *Transactions*
have been provided by
the Elizabeth F. McCoy Memorial Fund

Co-editors
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TRANSACTIONS OF THE WISCONSIN ACADEMY

Established 1870
Volume 73, 1985

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SEVERE THUNDERSTORM HAZARD IN WISCONSIN

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Abstract

This paper presents the results of a study of the spatial and temporal variations in severe thunderstorms and of two of the components—tornadic storms and hail—in Wisconsin. Results of factor analyses of the seasonal variations in the storm indices for each of the nine climatological divisions show that the seasonal migration patterns—from the southern portion of the state in spring toward the northwest in summer and back south in fall—are similar for thunderstorms in general, tornadic storms, and hailstorms, and reflect the seasonal migration and seasonal changes in the importance of different cyclogenetic regions and associated storm tracks across Wisconsin. The influence of these storm tracks is also reflected in the spatial distributions of the average annual storm indices by county which show two general regions of maximum activity for severe thunderstorms and the two components. Although lightning is the overall number one severe thunderstorm killer (total deaths/yr) for the state, the April tornado is highest in deaths per storm day.

INTRODUCTION

Severe thunderstorms generally occur in conjunction with squall lines ahead of cold fronts of extratropical cyclones. Since the development and direction of motion of cyclones is closely linked to the location of the jet stream, cyclone and severe thunderstorm activity and associated hazards—such as tornadoes, hail, and lightning—migrate with the season. Thus, maximum activity is located over the Gulf Coast in winter, it is in the central Great Plains in spring, and in the northern Great Plains and southern Canada in summer. The temperature contrast between polar and tropical air masses begins, however, to weaken in late spring which, in turn, is reflected in a weakened jet stream and reduced extratropical cyclone intensity. Consequently, the intensity as well as frequency of severe thunderstorms decreases as the area of maximum activity migrates northward. Thus, at the time of maximum thunderstorm frequency over the Canadian portion of the Great Plains, the number of days with thunderstorms observed there is only about three-quarters the number observed over the southern Great Plains of the United States. In fall, the temperature contrast intensifies again, and severe thunderstorm activity quickly retreats south toward the Gulf Coast (Kelly et al., 1978; McNulty et al., 1979).

Lightning kills more people in the United States—about 200 annually—than any other component of the severe thunderstorm hazard (Mogil and Groper, 1977). This may come as a surprise to some since lightning fatalities usually are single events that do not make national headlines. Most lightning deaths occur in the open where a person can serve as a relatively easy target; large structures and cars provide important protection from lightning strikes in urban areas. Tornadoes, on the other hand, account for only about 140 deaths annually (Mogil and Groper, 1977). Tornadoes vary, however, in their intensity and destructiveness: While extremely intense and violent tornadoes make up only about three percent of all tornado occurrences, they account for almost 70 percent of the deaths (Wilson and Morgan, 1971; Kessler and Lee, 1978; Kelly et al., 1978); and violent tornadoes tend to occur most frequently in spring.

The spatial and seasonal variations of the severe thunderstorm hazard components in the United States and some of their social costs are thus known in general terms. In addition, some studies have provided information on the climatology of hazard components at the state level, such as the work on tornadoes in Illinois (Wilson and Changnon, 1971), in Wisconsin (Burley and Waite, 1965), and in Michigan (Snider, 1977), or the work on hailstorms in Illinois (Changnon, 1960) and in Wisconsin (Burley et al., 1964). Many of the regional studies were, however, done more than a decade ago and have, similar to national studies, tended to focus on a single component of the severe thunderstorm hazard. The purpose of the present study is to develop a more comprehensive description of the spatial and seasonal variations in severe thunderstorms in Wisconsin by (1) analyzing these variations not only for severe thunderstorms in general but also for the two most reliably and widely reported components—tornadic storms and hailstorms; and by (2) interpreting the results in terms of the seasonal and spatial variations in their common generating mechanism—extratropical cyclones—and their tracks across Wisconsin. The state of Wisconsin is located near the northeastern margin of the center of severe thunderstorm activity; strong gradients across the state should therefore be present and make patterns relatively easily identifiable.

Data and Method

The source of the basic data used in this study was *Storm Data* (NOAA, 1959-) which provides information on all reported severe weather events by state and county. All Wisconsin events described as having been caused by or having occurred in association with thunderstorms were noted and comprise the basic data for this study. All of these events were, for the purpose of this study, considered 'severe thunderstorm' events. 'Tornadic storm' events, a subset of the 'severe thunderstorm' events, include all reports of tornadoes and/or funnel clouds. 'Hailstorm' events, also a subset of the 'severe thunderstorm' events, consist of all reports of hail. Excluded are winter storms that produced snow, freezing rain, or widespread strong winds, and flooding that was at least partly caused by snow melt.

The study covers the 24-year period 1959-1982. This period does not include the early 1950s when nationwide changes in reporting procedures and increased public awareness resulted in an abrupt increase in the reporting of weak tornadoes and thus in an increase in the total number of tornadoes (McNulty et al., 1979; Tecson et al., 1979). In the early 1970s, the reporting responsibility moved from the State Climatologist Office to the National Weather Service Forecast Office; there are, however, no significant changes in the number of reported storms for Wisconsin at that time.

The quality of the *Storm Data* listings has been questioned, particularly that for tornadoes. However, while the results of some investigations have suggested that not all tornado occurrences are observed and thus reported (Eshelman and Stanford, 1977; Snider, 1977; Schaefer and Galway, 1982) others have indicated that some reported tornadoes were actually straight-line winds associated with severe thunderstorms (Changnon, 1982). In spite of the limitations of *Storm Data,* it is still the best severe weather data base available.

The basic analysis of the spatial and temporal distribution of severe storms was done at the county level since *Storm Data* lists severe weather events by county. At the next level of aggregation, county data were summed over all counties within each of the nine climatological divisions of Wisconsin (Fig. 1); at the highest level of aggregation, county data were summed over all counties within the state.

For the present analysis, storm event reports were first converted into storm days per county. This was done because of differences in the size and duration of different types of storms which, for instance, permit very specific information on the location of tornadoes but only very general information for a line of thunderstorms moving across a portion of the state. Furthermore, there are occasional problems even with tornado reports: It is not always clear whether two separate reports from the same county actually represent two different tornadoes. If a storm affected more than one county, it was counted once for each county affected.

The probability of an event occurring in a county is a function of county size, while the probability of it being observed and reported is affected by rural population density. County size in Wisconsin ranges from about 600 km² to about 4000 km². In general, counties in the northern half of the state are larger than counties in the southern half (Fig. 1). Rural population density ranges from about 3 people per km² to about 48 people per km². Rural population density is generally highest in the southeastern portion of Wisconsin, reflecting the proximity of Milwaukee and Chicago; a secondary peak in rural population density is found in the west-central portion, reflecting the proximity of Minneapolis. In a nationwide study of population biases in tornado reports, Schaefer and Galway (1982) have found that Wisconsin's most densely populated counties report 1.25 times the number of tornadoes that would be expected if they were distributed uniformly across the state, while the least densely populated counties report only one-third the expected number. Each storm day was therefore standardized by converting it into a storm index, which was defined as

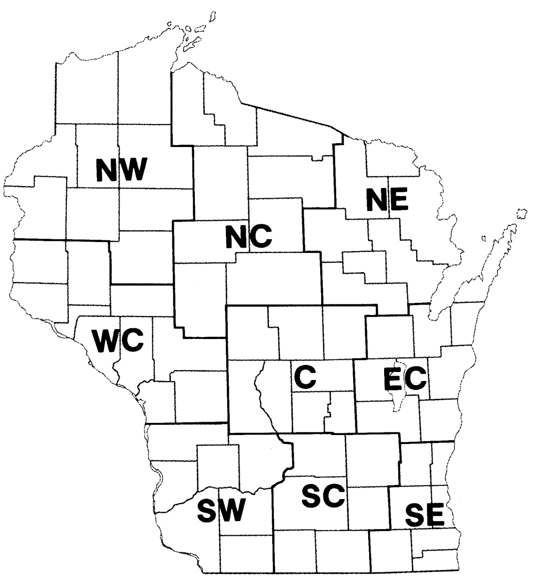

Fig. 1. The nine climatological divisions of Wisconsin.

$$\text{storm index} = \frac{\text{storm day}}{\text{county area * rural population density}}$$

Since rural population has in some cases increased by as much as 50 percent between 1960 and 1980, an estimate of the rural population for the year of the storm day was used to compute the storm index. Rural population for years between population census years was estimated by interpolating between years with census data.

The number of injuries and fatalities caused by a given storm is a function of the population-at-risk, or the total population density, of the county. Injuries were therefore standardized by converting each injury into an injury index, which was defined as

$$\text{injury index} = \frac{\text{injury}}{\text{total county population density}}$$

Deaths were standardized in the same way. Total population for the year in which the injury or death occurred was again estimated by interpolating between census years.

For some parts of Wisconsin—particularly Door County and North-Central Wisconsin—the population density increases considerably during the summer vacation season. Rough estimates by the Door County Chamber of Commerce and researchers at the University of Wisconsin-Extension (pers. comm.) of the size of the tourist population of Door County on the bases of the number of hotel rooms and summer homes and estimates of the average number of occupants of these rooms and homes suggest that it could, at times, be the size of the total permanent population of Door County. However, since neither average annual nor average monthly data on tourist population per county is available for the state of Wisconsin, it was not possible to include this population in the computation of the indices.

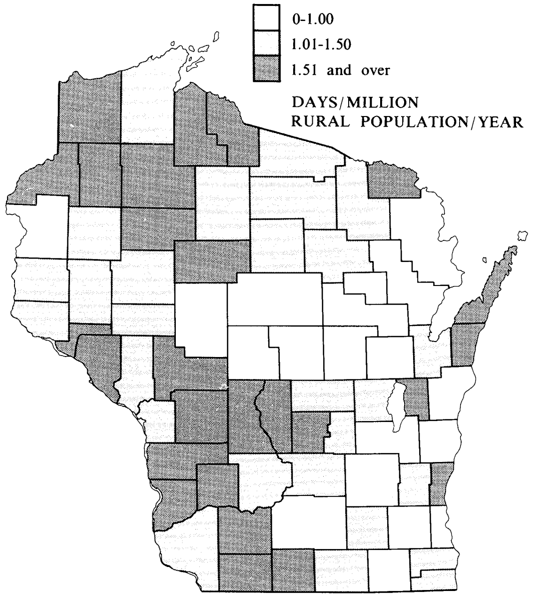

Fig. 2. Average annual severe thunderstorm index by county.

SEVERE THUNDERSTORMS

The spatial pattern of the average annual severe thunderstorm index by county (Fig. 2) shows two regions with relatively high values: A southern one which extends from the SW and WC divisions eastward and northeastward (hereafter referred to as the Southern Track), and a northwestern region which extends from the WC division northeastward (hereafter referred to as the Northwestern Track). One area of relatively low values, extending across the central and northeastern portion of the state, divides the two regions of maximum activity; another area of relatively low values covers portions of the western shore of Lake Michigan.

The seasonal variation in the severe thunderstorm index for the state is shown in Fig. 3. (This curve was obtained by summing the average index over all counties for each half-

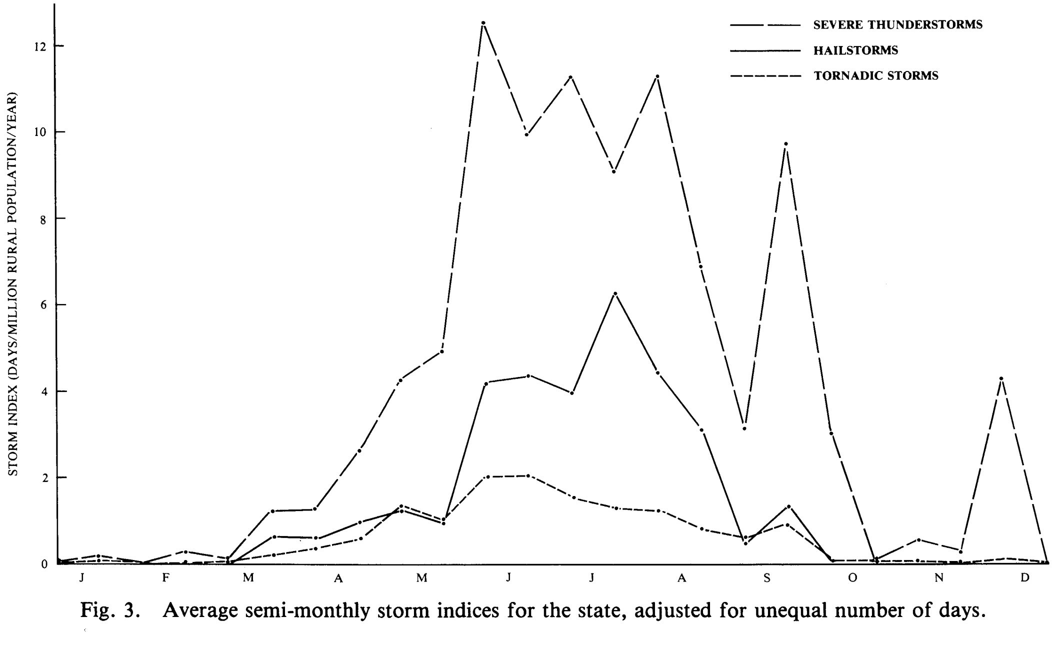

Fig. 3. Average semi-monthly storm indices for the state, adjusted for unequal number of days.

month: days 1-15 and days 16-the end. The data were adjusted for unequal length of the two halves. Since the index for the state is a summation over county-day indices, a high state index represents frequent and/or widespread activity.) The severe thunderstorm index for the state increases rapidly from late March through April and May, reaching its peak in early June. A relatively constant high level of activity persists through late June, July, and early August. It then decreases during late August and early September to a level similar to that of late spring. A drastic increase in activity to a summer-like level occurs briefly in late September. Another, but minor, peak occurs in early December.

There are, however, regional variations in the timing of the peak in severe thunderstorm activity. To quantify these regional variations, the average semi-monthly severe thunderstorm index was summed over all counties within each of the nine climatological divisions. The nine time series of the semi-monthly indices for the severe thunderstorm season, April through September, were then subjected to factor analysis to identify the most predominant temporal patterns. (More specifically, orthogonally rotated (varimax) factors were extracted from the covariance matrix.)

The first four factors of the divisional severe thunderstorm indices explain 84 percent of the total variance; the associated loadings are shown in Fig. 4. The first factor represents a July peak in severe thunderstorm activity; the second represents a May/early June and a late August peak; the third represents an early July and a late

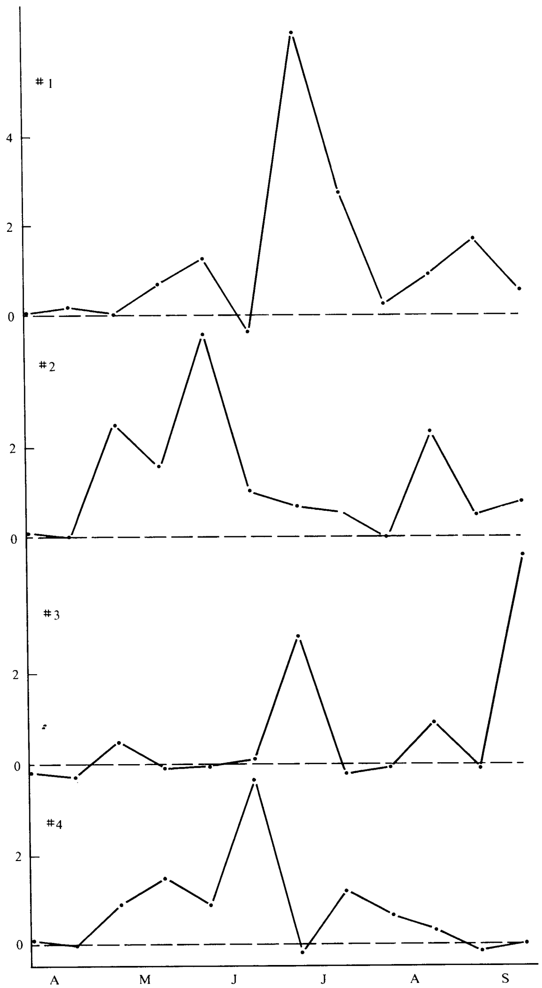

Fig. 4. Loadings for the first four factors of the severe thunderstorm index.

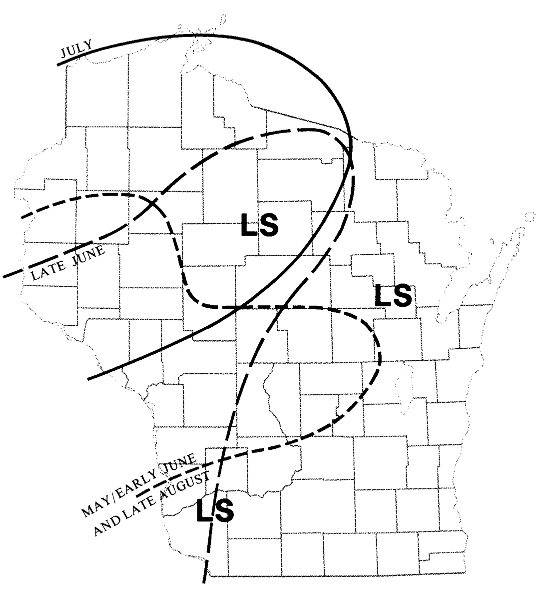

Fig. 5. Seasonal shifts in severe thunderstorm activity (LS = late September; based on the scores of the first four factors).

September peak; and the fourth represents a late June peak. (Minor peaks in the factor loadings, although important in the modulation of the divisional seasonal variations, are not considered here since the emphasis is on the most predominant temporal and spatial patterns.) The curve for the state (Fig. 3) is thus the result of several divisional curves with different seasonal peaks. The spatial patterns of the scores associated with each of the factors not only show these divisional differences but they can also be used to delineate seasonal shifts in the location of severe thunderstorm activity (Fig. 5; the lines delineate the general area experiencing a peak in activity at the indicated time or times).

In Wisconsin, severe thunderstorm activity begins in early spring over the southern portion of the state, but because of the still fairly low level of activity at that time, this beginning is not captured by the first four factors. In May and early June, the area of maximum activity is over the northern portion of the Southern Track; activity over the Northwestern Track is just beginning. In late June, it is over the southeastern portion of the Northwestern Track. By July, the region of maximum severe thunderstorm activity has reached its most northerly position, running across the northwestern portion of the state. By late August, it has shrunk back in the north but is quickly expanding southward and eastward across the northern portion of the Southern Track, to a position similar to its late spring position of May and early June. The southward migration of severe thunderstorm activity is, however, interrupted in late September when activity moves briefly back to a more northerly position, similar to that of mid-summer. This brief northward jump lacks, however, spatial uniformity; and the drawing of isolines is therefore not possible. Instead, divisions with late September peaks are labeled 'LS' in Fig. 5.

Tornadic Storms

The spatial pattern of the average annual tornadic storm index by county (Fig. 6) shows two regions with relatively high values which are similar to the two regions of maxi-

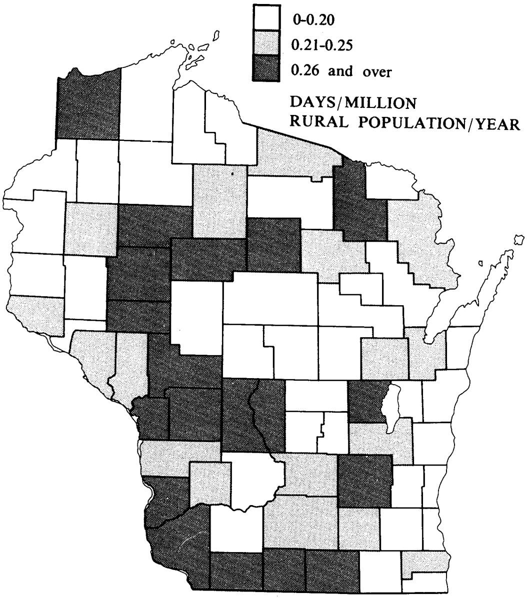

Fig. 6. Average annual tornadic storm index by county.

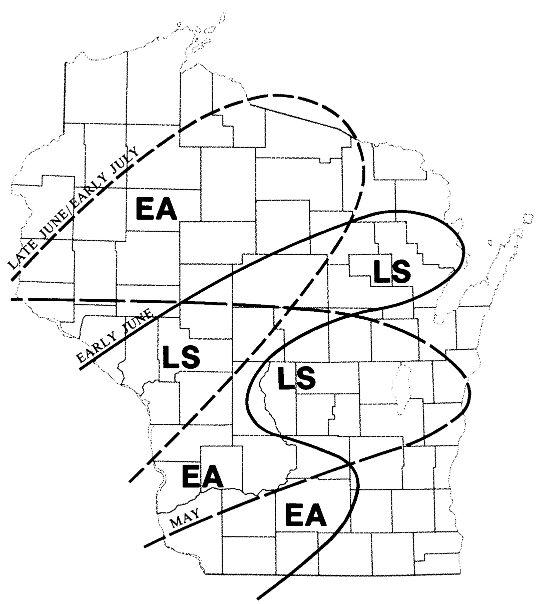

Fig. 7. Seasonal shifts in tornadic storm activity (EA = early August, LS = late September, based on the scores of the first four factors).

mum severe thunderstorm activity. A belt of minimum values runs southwest-northeast across the state, separating the two regions or tracks; another belt of minimum tornadic storm activity covers the western shore of Lake Michigan.

The seasonal variation in the tornadic storm index for the state is shown in Fig. 3. The index increases rapidly during the spring to a secondary peak in May and the main peak in June; this is followed by a gradual decrease during July, August, and early September. A small increase in the tornadic storm index occurs in late September.

The time series of the average semimonthly tornadic storm indices for each of the nine climatological divisions were subjected to factor analysis to identify divisional variations in seasonality. The loadings for the first four factors, which explain 89 percent of the variance, indicate that the tornado season peak for the state consists of several divisional peaks which are similar to the severe thunderstorm peaks. Early spring activity is, again, not captured by the first four factors because of the generally low tornado activity at that time of year. The spatial distribution of the factor scores (Fig. 7) indicate the following seasonal migration of tornadic storm activity: In May, maximum activity is located over the northern portion of the Southern Track. (When comparing the patterns in Fig. 7 with those for severe thunderstorms in Fig. 5, the slight differences in timing need to be considered.) In early June, the area of maximum activity has begun to shrink in the south and to expand in the north across the southern portion of the Northwestern Track. By July, it has reached its most northerly position, running from the WC division northeastward across the northwestern portion of the state. In early August, tornadic activity is rapidly shifting southward, In late September, however, it moves briefly back to a more northerly position.

Hailstorms

The spatial pattern of the average annual hail index by county (Fig. 8) is very similar to that for severe thunderstorms, consisting of a Southern Track and a Northwestern

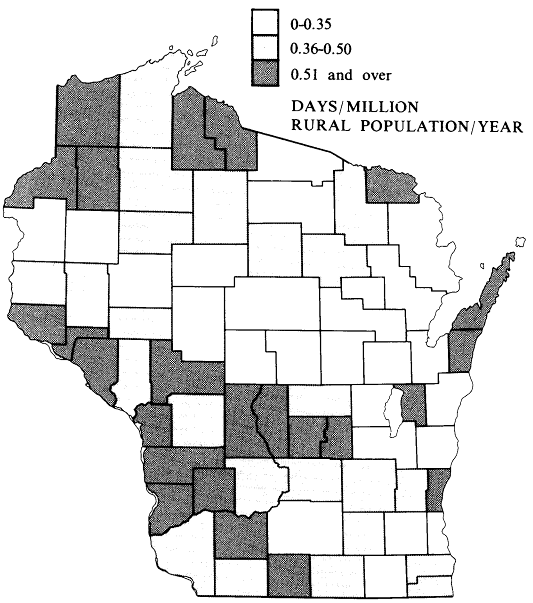

Fig. 8. Average annual hail storm index by county.

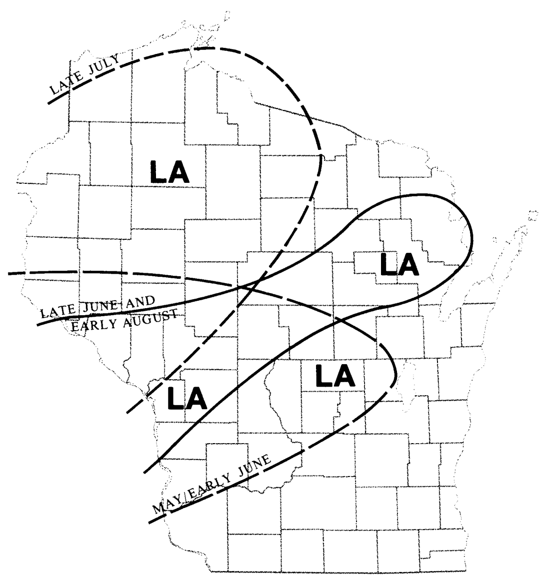

Fig. 9. Seasonal shifts in hail storm activity (LA = late August; based on the scores of the first four factors).

Track; an area of minimum activity divides the two tracks, another area of minimum activity covers portions of the western shore of Lake Michigan.

The seasonal variation in the hail index for the state is shown in Fig. 3. The index is low in spring. In early June, there is an abrupt increase in hail activity to a level that is maintained through most of June and early July. The main peak in hail activity occurs in late July and is followed by a relatively rapid decrease during August and September. A small increase occurs in late September.

Factor analysis of the nine divisional time series of the hail index indicate a seasonal migration similar to that for severe thunderstorms and tornadic storms (Fig. 9): During the early part of the main hail season (May/early June), maximum activity is over the Southern Track. In late June, activity decreases in the south while activity in the northern portion expands eastward. By July, it has reached its most northerly position, running across the northwestern portion of the state. By August, hail activity is rapidly migrating southward again.

Deaths and Injuries

Of the average annual severe thunderstorm death index for the state, over 50 percent is caused by lightning, 34 percent by wind and rain, and only 15 percent by tornadic storms. This reflects not only the frequency and severity of severe thunderstorms in Wisconsin but also the state's many lakes and the vast forested regions of northern Wisconsin. There are, however, some regional variations in the cause of death. While lightning is the main cause of death for the northern divisions (where fishing, boating, and hunting are major tourist attractions), rain and wind—particularly drowning—tend to be more important in the more densely populated southern divisions.

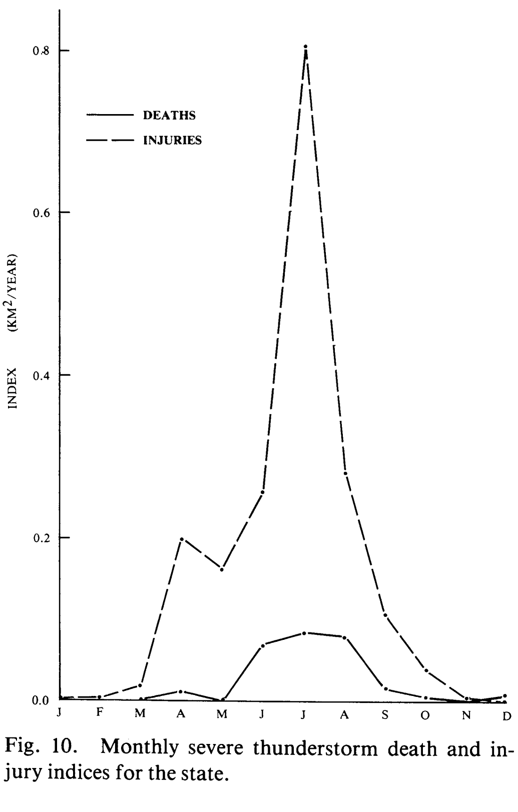

Fig. 10. Monthly severe thunderstorm death and injury indices for the state.

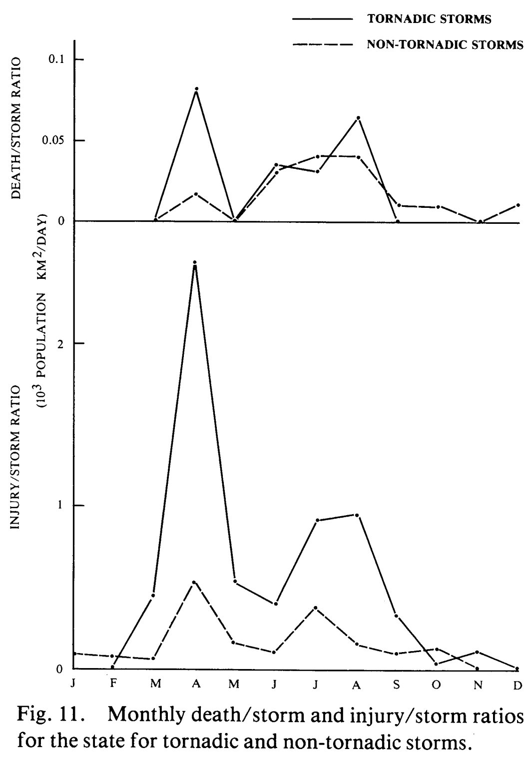

Fig. 11. Monthly death/storm and injury/storm ratios for the state for tornadic and non-tornadic storms.

Tornadic storms are a secondary cause of death everywhere in the state, but they are the primary cause of injuries. Of the average annual severe thunderstorm injury index for the state, over 50 percent is caused by tornadic storms, 32 percent by wind and rain, and only 16 percent by lightning. These proportions are about the same everywhere in the state.

The average monthly severe thunderstorm death and injury indices (Fig. 10) increase during spring, reach a peak in summer, and then decrease again in fall. These changes reflect, to a large degree, the seasonal changes in the occurrence of severe storms.

To remove the effect of seasonal variations in the occurrence of storms, death-storm and injury-storm ratios were computed, defined as the death or injury index for the state divided by the storm index for the state (Fig. 11). Both the death-storm and injury-storm ratios are highest for tornadic storms occurring in April. During the remainder of the severe thunderstorm season, the death-storm ratios for tornadic and non-tornadic storms are comparable in magnitude while the injury-storm ratios for tornadic storms are somewhat higher than those for non-tornadic storms.

Summary and Discussion

The severe thunderstorm season starts in Wisconsin in early spring and reaches its peak in June, July, and early August. A secondary maximum occurs in late September. During the storm season, the area of maximum activity migrates across the state. The migration pattern is, however, not a simple north-south shift as would be expected from the generalized and simplified view of a north-south migration of the jet stream and cyclone tracks across the country. Instead, the migration pattern—which is very similar for severe thunderstorms in general, for tornadic storms, and for hailstorms—is from the southern portion of the state toward the *northwest* and back, which reflects seasonal changes in the degree of activity over the two main cyclone tracks affecting Wisconsin (Whittaker and Horn, 1984). In spring, cyclones generated over the Great Basin and Colorado move northeastward and affect the southern and eastern portion of the Great Lakes Basin; in summer, cyclones generated over Wyoming and Alberta affect the northwestern portion of the Great Lakes Basin before heading northeastward to James Bay.

Activity begins in early spring when one of the primary North American extratropical cyclone tracks, extending from the Great Basin/Colorado cyclogenetic area eastward, shifts northward and reaches southern Wisconsin. Severe thunderstorm activity is still fairly low at that time of year, and severe thunderstorm-related deaths and injuries are therefore also still fairly low. Tornadic storm and hail storm activity is also low but, because of the relatively low severe thunderstorm activity, as much as one-third of the severe thunderstorm index is tornado activity and another one-third is hailstorm activity. The tornadic storms are, furthermore, extremely intense and destructive at that time of year. No severe thunderstorm component at any other time during the season causes as many deaths and injuries per storm day as the tornadic storm in April.

By May, the area of maximum activity extends from the southwest and west eastward across the southern portion of the state. Severe thunderstorms are increasing, but tornadic storms and hailstorms are increasing as well so that each still comprises about one-third of the severe thunderstorm index. Severe thunderstorm-related deaths and injuries are still relatively low; and tornadic storms become less intense and destructive as the temperature contrast between polar and tropical air masses decreases.

By June, the Great Lakes Basin comes increasingly under the influence of eastward and southeastward tracking Alberta and Northwest Territory cyclones. The severe thunderstorm activity pattern in Wisconsin takes on a two-pronged appearance, with activity over the Southern Track decreasing and activity over the Northwestern Track increasing. Severe thunderstorm activity is thus widespread and high; hailstorm activity represents about 37 percent of the severe thunderstorm activity; while tornadic storm activity, although at its peak, comprises only about 20 percent of the total activity. Severe thunderstorm-caused deaths and injuries are also high. Drowning and other water-related deaths (an important cause of death in the southern third of the state) reaches its peak in June, while lightning deaths continue to increase into July.

In July, the Colorado and Great Basin cyclogenetic areas become inactive, and only Montana and Alberta cyclones, swinging eastward and southeastward before converging over James Bay, affect the northwestern portion of the Great Lakes region. In Wisconsin, maximum severe thunderstorm activity is located in a belt running across the northwestern portion of the state. Severe thunderstorm activity as a whole is still high; hail activity is at its maximum and now comprises more than half the severe thunderstorm activity; while tornadic storm activity is declining. Deaths and injuries caused by severe thunderstorms are at their peak; in particular, deaths caused by lightning—the number one severe thunderstorm killer for the state and particularly for the northern third of the state—are most frequent in July. Tornadic storms, on the other hand, are responsible for only 15 percent of the deaths but over 50 percent of the injuries in July.

In August, cyclogenetic activity along the Rocky Mountains begins to extend southward again and the more southern tracks across the country become increasingly active. Severe thunderstorm activity in Wisconsin begins a rapid and irregular retreat to a late spring-early summer position: Activity decreases over the Northwestern Track and expands eastward in the south. Severe thunderstorm activity is still relatively high but declining. Hailstorm and tornadic storm activity are also rapidly decreasing, with hail representing about 38 percent of the total storm activity and tornadic storms making up 10 percent. Deaths and injuries are decreasing as well.

By early September, there is a drastic decrease in severe thunderstorm activity. Activity increases, however, briefly in late September to a mid-summer level and shifts northward to a mid-summer like pattern. But the activity is not very intense: Little of it produces tornadic storms or hail, and deaths and injuries per storm day are much below their mid-summer levels.

Not only is this seasonal migration pattern a reflection of the influence of the two extratropical cyclone tracks across Wisconsin but the spatial patterns of the average annual severe thunderstorm activity are also a reflection of these two tracks. The patterns for severe thunderstorms in general as well as those for tornadoes and hail show two general areas of maximum activity: one across the southern portion of the state, the other across the northwest. An important region of activity for severe thunderstorms, tornadic storms, and hail storms is the WC division where the influence of the two cyclonic storm tracks appears to overlap.

A belt of minimum activity separates the two maxima. This belt could be the northern end of the slanted 'trough' line identified by Tecson et al. (1982). This line is a slanted narrow line of minimum tornado occurrence—extending from southern Texas to Upper Michigan and dividing Wisconsin into a northwestern and a southeastern half—that separates 'eastern' from 'western' tornadoes. Eastern tornadoes become active in Mississippi in February; from there they spread northward; peak activity is in March and April. Western tornadoes, on the other hand, become active in the Tornado Alley in April and reach their peak in May; activity then decreases while they spread northward toward the Canadian border. The present results, which show such a trough line not only in the distribution of tornadoes but also in the distribution of hail and severe thunderstorms in general, suggest that the cause of this line may have a synoptic basis, rather than topographic or population-related bases as has been suggested.

Another area of minimum activity in severe thunderstorms in general as well as in tornadic storm and hailstorm activity, extending along the western shore of Lake Michigan, is caused by the relatively low temperature of the surface water during spring and summer which suppresses convective activity.

Acknowledgements

This work was supported by the Wisconsin Alumni Research Foundation.

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PREGLACIAL RIVER VALLEYS OF MARQUETTE, GREEN LAKE, AND WAUSHARA COUNTIES

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Abstract

Buried preglacial river valleys lying in three Wisconsin Counties were identified and mapped. Their physical dimensions were obtained by way of a mathematical model that was used to describe a valley cross section. The network of buried valleys that was discovered corresponds in part with the successive damming of the ancient Wisconsin River by the advancing and most recent glacier. The underlying Precambrian bedrock apparently influenced the glacier's direction of movement as well as the courses of some of the preglacial rivers in this region.

Introduction

In preglacial times, the ancient Wisconsin River flowed from the northern highland of Wisconsin and Michigan southward into central Wisconsin. There it had carved out of the Baraboo hills the famous Devils Lake gorge and, turning westward at Merrimac, concluded its journey at Prairie du Chien where it met the ancient Mississippi River (Martin, 1932). If glaciation had never occurred, the modern Wisconsin River would still be following this course, but the invasion of the last continental glacier squeezed the Wisconsin River out of its ancient valley in central Wisconsin and permanently diverted its flow to its modern valley bordering Adams and Juneau Counties (Alden, 1918). Prior to glaciation, the ancient river made a great loop in central Wisconsin which extended from the vicinity of Friendship to Green Lake before it entered the gorge at Devils Lake. Neither the loop nor the gorge are used by the river today.

Even though glaciation had significantly scoured the land, the buried bedrock underlying Marquette, Green Lake, and Waushara Counties still has etched in it the preglacial river valleys that once contained the Wisconsin, Wolf, and Fox Rivers. The existence of these buried preglacial valleys has been known for more than one hundred years; their presence, however, is inconspicuous and their exact locations can only be found by means of well drillings and borings. Occasionally, the top of an ancient valley is visible, but, generally, the valleys are completely buried beneath glacial drift. On top of the drift lacustrine deposits have created, along practically all these ancient valleys, the wetlands that abound in these three counties.

Immediately prior to the four Pleistocene glaciations that are known to have touched Wisconsin (USGS, 1976), most of the limestone bedrock that once uniformly covered this region had already eroded away (Martin, 1932). Rolling hills of sandstone dotted with crags, buttes, and pinnacles were features of the preglacial landscape as they are in the landscape of the Driftless Area of Wisconsin today. In preglacial times, the Wisconsin River was one of the largest rivers in Wisconsin. In central Wisconsin, its valley was approximately 600 feet deep and 4 miles wide at the crests. The river entered Marquette County from the west in the town of Westfield, at an elevation of 503 feet above sea level with respect to the bottom of its channel, and proceeded eastwardly on the first leg of a great loop as shown in Fig. 1. The Wisconsin River met the ancient Wolf River at Neshkoro and the ancient Fox River at Green Lake, the eastern extreme point of

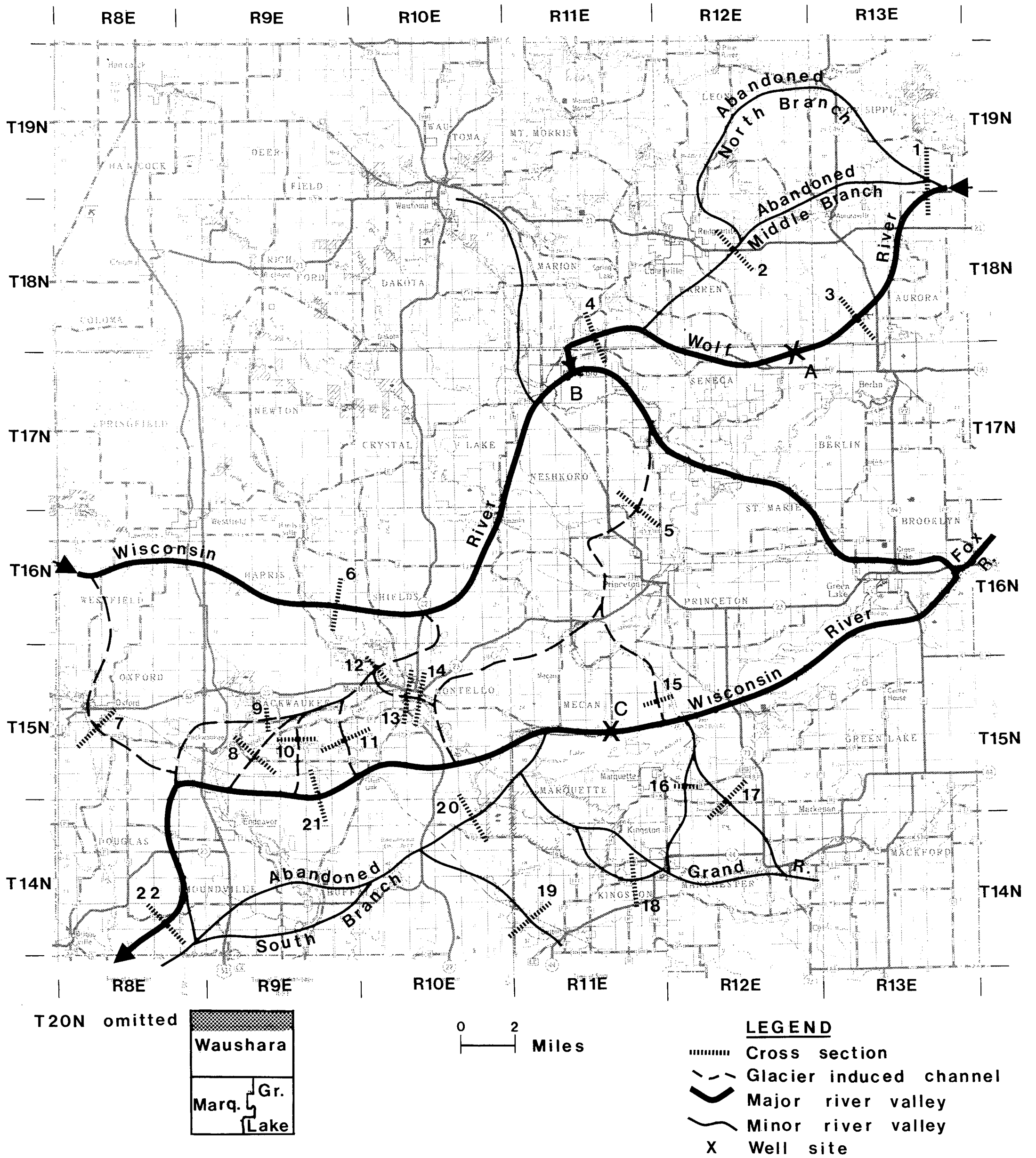


Fig. 1. Map of preglacial river valleys of the Wisconsin, Wolf, Fox, and Grand Rivers. The three wells A, B, and C are listed in Table 1. The twenty two cross sections of the river valleys and channels are listed in Table 2.

TABLE 1. Important Wells Marked in Figure 1.

Well	*Elevation of bottom above sea level*
A	473 feet
B	462
C	420

the loop. Turning abruptly to the west at Green Lake, the Wisconsin River, on its westward course, dug the basins in which Green Lake and Lake Puckaway lie. It reentered Marquette County on the last leg of the loop and, in the town of Douglas, left the county at an elevation of 382 feet above sea level enroute to the Devils Lake gorge 20 miles away.

History

The history of the Fox River in central Wisconsin was probably first discussed by John Petitval in 1838. In his report to Congress of the survey of the Fox River, he speculated that the upper Fox River valley had at one time been a chain of lakes which suddenly drained, leaving the Fox River as a meandering stream. In 1876, Warren submitted to Congress a more comprehensive geologic report of the Fox River. In that report, Warren asserted that the Fox River in preglacial times had flowed in the opposite direction and had actually been a tributary of the ancient Wisconsin River. According to Warren, their confluence was located at Portage, while the ancient Wisconsin River, as Warren tacitly assumed, followed the same course as the modern Wisconsin River follows.

In 1877, Irving's treatise on Wisconsin geology was published, yet it did not contain any more information than Warren's report about the history of either the Wisconsin or Fox Rivers. Forty years later, though, William Alden squarely addressed the topic of ancient river valleys in *The Quaternary Geology of Southeastern Wisconsin,* published in 1918, and his opinion about the ancient Wisconsin River has been the authoritative one ever since. He offered two conjectures pertaining to the course of that ancient river. The first was that the confluence of the ancient Wisconsin and Fox Rivers was located in the town of Oxford where the Wisconsin River, flowing southeastwardly through the village of Oxford, joined the Fox which was flowing westwardly through Rush Lake, Green Lake, and Lake Puckaway. The second conjecture was that the Wisconsin River had flowed directly south from Stevens Point through Wautoma and Neshkoro to meet the Fox in Oxford. Relying on Alden's work, E. F. Bean apparently incorporated Alden's second conjecture into his *Geologic Map of Wisconsin,* published in 1924, by drawing a narrow trigger shaped contour depicting an extension of the exposed Precambrian bedrock of Portage County through Waushara County and well into Marquette County as if that extension was the exposed granite of the ancient Wisconsin River bottom. (For an illustration, see Martin, p. 35). This narrow trigger shaped contour of Precambrian rock is a characteristic mark of Bean's map and has been reproduced in many publications since; nevertheless, the existence of it can not be substantiated and it no longer appears on the latest map of the geology of Wisconsin (Mudrey, 1985). The erroneous belief that the ancient Wisconsin River had flowed south from Stevens Point through Waushara County and Neshkoro Township to meet the Fox River in Oxford, as Alden had hypothesized and to which Bean alluded, was reiterated by Lawrence Martin in *The Physical Geography of Wisconsin,* published in 1932. There the issue remained at rest until 1976, when Mark Stewart wrote his doctoral thesis. In that thesis, Stewart presented a map of the preglacial Fox-Wolf River basin that finally delineated the course of the ancient Fox and Wolf Rivers in Green Lake and Marquette Counties with a good deal of accuracy.

Discussion of the Data

For the purpose of this article, the information obtained from the Wisconsin Department of Natural Resources well constructor's reports, from the Wisconsin Department of Transportation highway test borings, and from Alden (1918) provided 780 data points upon which the locations of the preglacial river valleys were deduced.

The data points were scattered over an area encompassed by the mapping of the bedrock topography shown in Fig. 2 and which equaled approximately 1,000 square miles. Even though very few wells ever reached the bottom of a river valley, the information obtained from many other neighboring wells provided sufficient circumstantial evidence to permit, by means of an appropriate mathematical model and standard statistical methods, an accurate description of the sizes and locations of the preglacial river valleys.

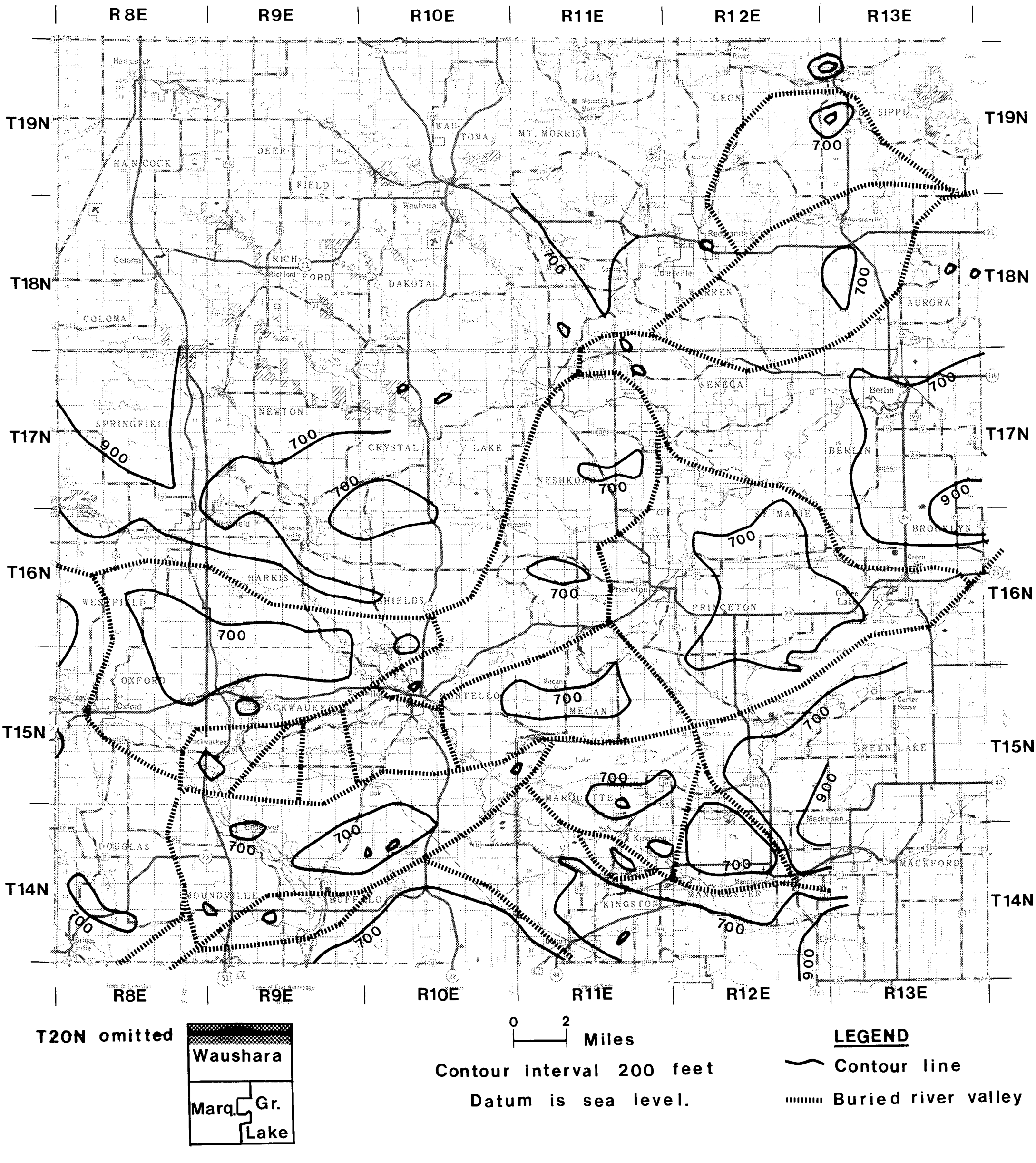


Fig. 2. Topographic map of the bedrock of Marquette, Green Lake, and southern Waushara Counties. It is based on data found primarily in well constructor's reports.

Knowing the dimensions of the river valleys helped to discriminate between what was a tributary, a glacier induced channel, and the main Wisconsin River valley itself. The analysis revealed a complex network of buried river valleys which was a result, in part, of the glacier's movement across this region.

The direction of glacial striae, the axes of drumlins, and the trend of surface soil types and features are telltale signs indicating a glacier's direction of movement. Soil surveys of Marquette and Green Lake Counties, published by the United States Department of Agriculture, delineated the boundaries of soil types and soil features on aerial photographs. (The soil survey of Waushara County (1909) is out of print and was not available). The direction of the longitudinal axis of a drumlin and the trend of soil features as outlined on the aerial photographs represent vectors of the glacier's movement.

The soil surveys of Green Lake and Marquette Counties utilized 69 non-overlapping aerial photographs. Each photograph was divided into two equal parts and each half constituted a separate sample area. On the average, seven vectors were drawn at random from each sample area. Some sample areas were rejected because they happened to cover an area too small to conduct a satisfactory sampling. The number of useful sample areas totaled 134 from which 921 vectors were drawn and used to ascertain the direction of the glacier's advance.

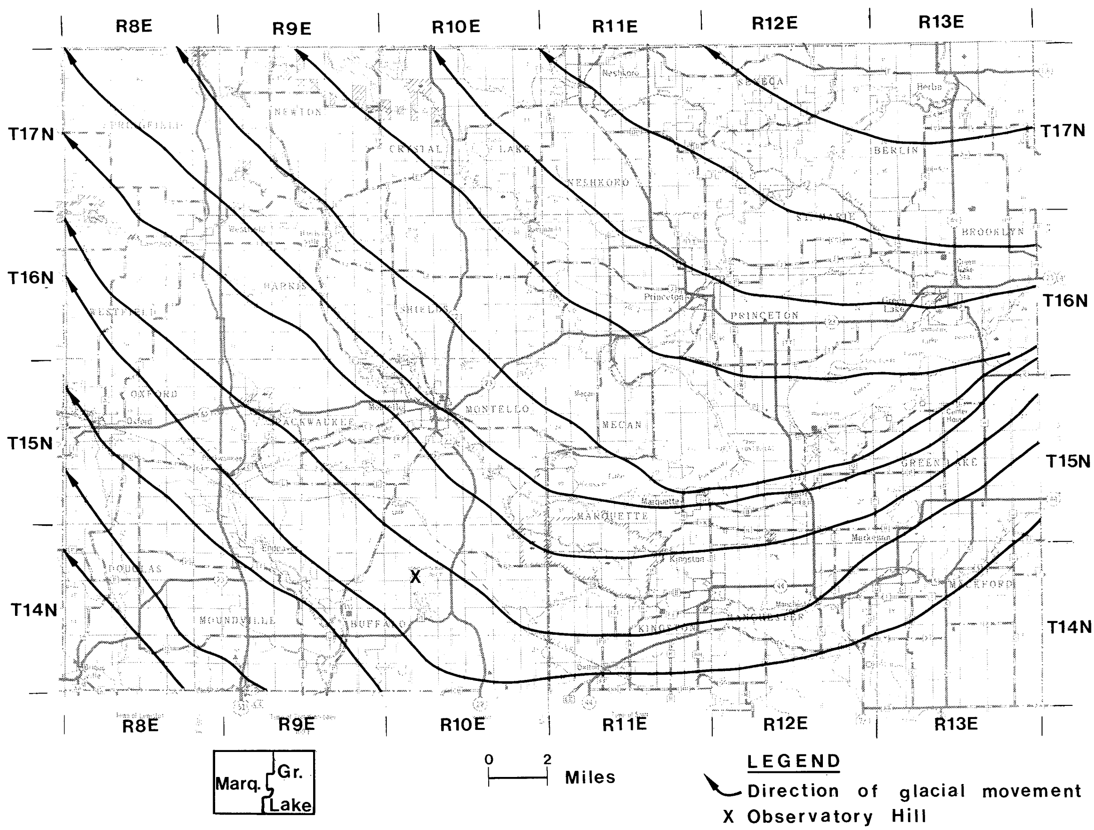


Fig. 3. Movement of the Green Bay Lobe of the continental glacier. Surface soil features indicated on USDA soil survey aerial photographs were used to map the direction of movement of the glacier. The glacier moved on a bearing of approximately 46° west of north through Marquette County.

The horizontal township lines of the Wisconsin coordinate system served as the reference lines throughout the task of measuring the direction of each vector. The angle which a vector made with one of these lines was considered a random variable with a common variance. Actually a different variance could have been associated with each sample area but, because the surface soil features indicating the direction of the glacier's movement were made by the same ice sheet, a common variance was assumed. In each sample area, A_j, the i^{th} vector made an angle θ_{ij}, with a township line. For each A_j, the sample mean, $\bar{\theta}_j$, was computed by the formula: $\bar{\theta}_j = \frac{1}{n_j} \sum_{i=1}^{n_j} \theta_{ij}$, where n_j is the number of vectors drawn from the sample area, A_j. Parallel lines of slope tan $(\bar{\theta}_j)$ were assigned to each A_j for every j in order to make a field of tangents. The resulting envelope of these lines is represented by the lines of movement which are outlined in Fig. 3. The direction of the glacier's movement, obtained in this manner by piecing together the trend of surface soil features of one sample area with another, still retains the uncertainty inherent to the data. The variance, σ^2, of the random variable, θ_{ij}, was assumed, as previously noted, to be the same for all i and j. It was estimated by the mean sum of square errors, as follows:

$$\hat{\sigma}^2 = \frac{1}{N\text{-}k} \sum_{j=1}^{k} \sum_{i=1}^{n_j} (\theta_{ij} - \bar{\theta}_j)^2$$

where $N = \sum_{j=i}^{k} n_j$ and k is the number of sample areas; specifically, k = 134, N = 921, and σ^2 = 75.4. The standard deviation of ±8.7° indicates how much the direction of a vector varies about the mean direction of a sample area.

Presumably, the surface soil features in this region owe their existence to the most recent glaciation and subsequent weathering. If previous glaciers had covered the area, then the soil features made by them would have been obliterated by a succeeding glacier. The Wisconsin stage of glaciation is the most recent of the four Pleistocene glaciations that have touched Wisconsin. According to Maher (1982), the Green Bay Lobe of that glaciation disappeared from Marquette and Green Lake Counties approximately 12,400 years ago.

Based on the orientation of drumlins and other surface features which the Green Lake Lobe created, the direction of movement of the glacier in Marquette and Green Lake Counties, as outlined in Fig. 3, agrees with the direction of glacial striae reported by Alden (1918) at a level of significance of 0.05. This high degree of correlation between the direction of glacial striae reported by Alden and the surface soil features forming the basis of Fig. 3 suggests that both the striae and soil features were made by the same glacier.

As the Green Bay Lobe moved south from Green Bay, it simultaneously expanded laterally to the west, so that in Marquette County the glacier actually moved from the southeast to the northwest (Fig. 3). In so doing, as the ice advanced, it encountered the eastern extent of the Wisconsin River and dammed it (Fig. 4). When the resulting impoundment overflowed, the water cut a new channel. In time, a total of eight drainage channels were cut (Fig. 1). The presence of well defined channels indicates that each was used for many years, perhaps for centuries at a time, in order for the impounded Wisconsin River to erode away an average of 200 feet of sandstone for each drainage channel.

Mathematical Model

To find the physical dimensions of a valley, the shape of each valley cross section was described by a mathematical model from which the depth, width, and other characteristics were found. The model consists of three parabolas joined together in a manner that ascribed a parabolic shape to the sides and bottom of a hypothetical valley

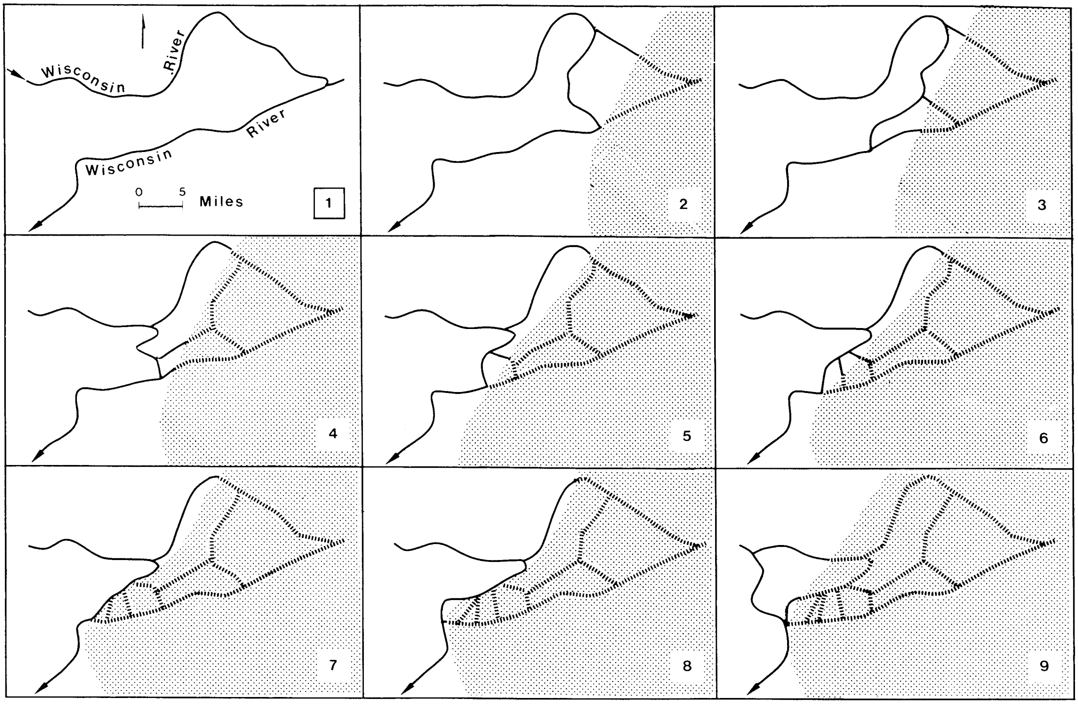


Fig. 4. Stages portraying the sequential damming of the ancient Wisconsin River by the advancing glacier. Stage 1 shows the course of the Wisconsin River before glaciation; it is the same course shown in Fig. 1. Stages 2 to 9 depict a possible association of each drainage channel with the terminus of the glacier. The glacier is shown by the dotted pattern. The dashed lines show the valleys buried under the ice. The area in this figure covers Marquette and Green Lake Counties.

cross section. The model cross section was defined by the following equations:

$$y_{I} = a(x-b)^2 + c \qquad b \leq x \leq x_2 \qquad (1)$$

$$y_{II} = p(x-e)^2 + q \qquad x_2 \leq x \leq s \qquad (2)$$

$$y_{III} = a(x-d)^2 + c \qquad s \leq x \leq d \qquad (3)$$

where $s = 2e - x_2$ and is based on the stipulation that the cross section be bilaterally symmetrical. The purpose for dwelling on the derivation of a mathematical model arises from the chance to exploit the information supplied by that special circumstance wherein a buried valley is spanned by three water wells (Fig. 5). In this particular situation, the wells happen to bracket the location of the bottom of a valley and the elevations of the bottoms of the wells indicate the degree of curvature of a valley wall.

As will be seen, there is not enough data available to obtain a complete mathematical description of a hypothetical valley cross section as proposed via equations (1), (2), and (3), unless some artificial constraint is imposed upon the model. There are many con-

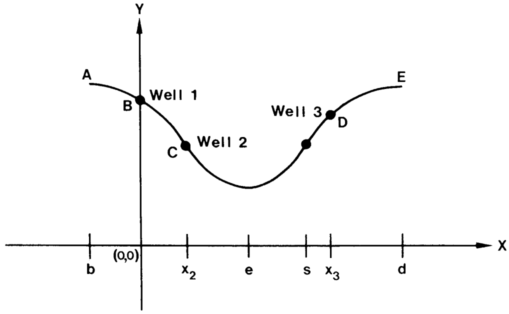


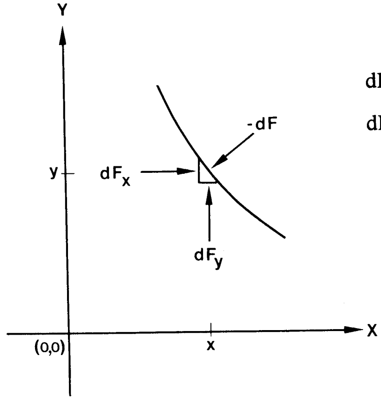
Fig. 5. Hypothetical valley cross section. The relative locations of the wells must be observed when using the equations found in the text.

ceivable constraints that could be used to make the model work, but the one given below by equation (7) worked very well.

The model so described by equations (1)–(3) requires the numerical solution of seven unknown parameters and hence the formulation of seven independent equations from which a unique solution may be obtained. From time to time, three water wells did line up to span a valley as illustrated in Fig. 5 and gave rise, thereby, to three equations. To obtain the necessary seven equations, four constraints were imposed on the model so as to complement the equations already provided by the three wells. The first two constraints that were chosen impose on the model the continuity from A to E (Fig. 5) which would naturally exist and the bilateral symmetry needed to make a simple second order model simpler. (The bilateral symmetry which was sought for the cross section warranted the condition, $e=(b+d)/2$). For the third constraint, parabolas I and II were appropriately joined at C to make the first derivative continuous all along the curve.

At this point, we have imposed three constraints on the model with one more to go. If, by good fortune, the buried river valleys were to have been spanned geographically by four wells lying in a straight line instead of the three, then all of the necessary information would be at hand. But, since the chance of having four wells drilled as such did not occur and because an arrangement of that kind frequently did occur with three water wells, a special constraint had to be found that would fulfill the requirement needed to arrive at seven independent equations and which would at the same time reasonably incorporate into the mathematical model some aspect of nature.

Recognizing that the forces acting on a valley wall must balance in order to preserve static equilibrium, the internal forces that bind the wall together were presumed to be equal and opposite to the outward forces that act to tear the wall apart. The outward forces acting on a valley wall are, in general:



$$dF_x = P(x,y)\,dy$$
$$dF_y = P(x,y)\,dx$$

where $P(x,y)$ is the cumulative effect of the weathering and the pressure pushing outwardly at (x,y) due to the weight of the wall. The resultant force is $dF = P(x,y)\,dS$, where $dS = \sqrt{dx^2 + dy^2}$. Taking into account the assumption that the outward forces are equal and opposite to the internal binding forces, the resultant shearing force, dV, is:

$$dV = -P(x,y)\,dS$$

The function $P(x,y)$ took the form of

$$P(x,y) = P_o\frac{(S_1 + S_3)^2}{4S_1S_3}$$

where P_o is a constant and S_1 is the length of arc AB and S_3 is the length of DE. For example.

$$S_1 = -\frac{b}{2}\sqrt{1+4a^2b^2} - \frac{\sinh^{-1}(2ab)}{4a}$$

It was reasoned that the nearer the points B and D lie to one of the valley's crests, the more pronounced the shape of the valley, and therefore the greater $P(x,y)$ ought to be. In the other extreme case, it was reasoned that $P(x,y)$ should approach some constant, P_o, when the valley becomes very shallow. Consequently,

$$dV = -P_o\frac{(S_1+S_3)^2}{4S_1S_3}dS$$

$$\text{or } V(x) = -P_o\frac{(S_1+S_3)^2}{4S_1S_3}S(x) \quad b \leq x \leq d \qquad (4)$$

where $S(x) = \int_b^x dS$ and is the length of the arc (Fig. 5) beginning with abscissa b and ending with x; $S(x) \cong x\text{-}b$.

Drawing upon the study of the strength of materials, the energy, U, associated with the deformation of the valley walls due to shearing is:

$$U = \frac{k}{A}\int_b^d V_y^2(x)\,dx \tag{5}$$

where k is some constant, $V_y(x)$ is the vertical component of V(x), and A is the cross sectional area above the bottom of the valley;

$$V_y(x) \cong \frac{(c\text{-}q)}{(e\text{-}b)} V(x)$$

$$A \cong a(x_2\text{-}b)(e\text{-}b)^2 \tag{6}$$

The final and fourth constraint that we want to impose on the model dictates that the energy, U, be a minimum.

In the course of the mathematical development, it was convenient to express the parameters of equations (1)–(3) in terms of e, the mid-point of the valley, as follows:

$$a = \frac{(y_3\text{-}y_1)x_2 + (y_2\text{-}y_1)(x_3\text{-}2e)}{x_2(x_3\text{-}2e)(x_2 + x_3\text{-}2e)}$$

$$b = \tfrac{1}{2}\ \frac{(y_3\text{-}y_1)x_2^2 - (y_2\text{-}y_1)(x_3\text{-}2e)^2}{(y_3\text{-}y_1)x_2 + (y_2\text{-}y_1)(x_3\text{-}2e)}$$

$$c = y_1 - ab^2$$

$$d = 2e\text{-}b$$

$$p = a\,\frac{(x_2\text{-}b)}{(x_2\text{-}e)}$$

$$q = a(x_2\text{-}b)(e\text{-}b) + c$$

where y_1, y_2, and y_3 are the elevations above sea level of the bottoms of wells 1, 2, and 3 respectively. The relative locations of the water wells to e shown in Fig. 5 must be met in order to make the above expressions valid.

With the parameters expressed in terms of e, the task of obtaining the physical dimensions of a valley reduces to choosing e such that U, from equation (5), is minimized. In other words, the problem amounts to solving the equation

$$\frac{dU}{de} = 0 \tag{7}$$

where, from equations (4)–(6),

$$U \cong \frac{kP_o(d\text{-}b\text{-}x_3)^4\, a(x_2\text{-}b)(e\text{-}b)}{6\, b^2(d\text{-}x_3)^2}$$

The solution of equation (7) which requires the use of numerical analysis pertains to that situation when, according to the model, the locations of three water wells are co-linear and they happen to span a buried valley.

To check whether or not the model adequately explains the data, a diagnostic plot of residuals versus predicted values generated by the model was made and is given in Fig. 7. The observed values are the elevations above sea level of the bottom of those wells that came into the path of a rotated cross section. The original cross sections were all rotated about their mid-points to make them perpendicular to a valley. Sometimes one of the nearby wells would intersect the rotated cross section and as a result would supply a data point with which to check the adequacy of the model. The funnel shaped pattern exhibited in Fig. 7 indicates a

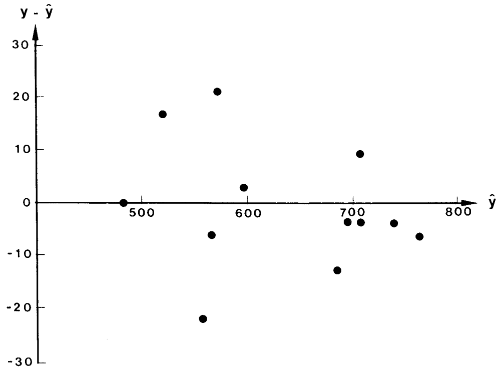


Fig. 7. Plot of the residuals versus predicted elevations above sea level from the model. An observed value is denoted by *y* and a predicted value by *ŷ*. Both coordinate axes are marked in units of feet. The funnel shaped pattern indicates a possible correlation between the expected elevation and variance.

TABLE 2. Parameters of Valley Cross Sections

Cross section[1]	a[2]	*Elevation of crests above* sea level	*Elevation of bottom above* sea level	*Width* at crests
1	−30.4 feet/mi²	760 feet	475 feet	6.3 miles
2	−64.3	699	515	4.2
3	−67.9	731	486	4.1
4	−183.0	788	447	3.0
5	−154.0	696	535	2.3
6	−125.0	721	485	3.5
7	−36.1	935	576	6.6
8	−77.0	807	469	4.3
9	−48.0	787	429	6.0
10	−86.7	654	491	2.8
11	−77.0	723	549	3.5
12	−47.3	687	552	3.5
13	−1152.0	991	477	1.4
14	−1140.0	681	442	1.0
15	−723.1	638	519	1.4
16	−267.0	805	577	1.9
17	−95.0	837	674	2.7
18	−241.0	831	492	2.5
19	−302.0	813	592	1.7
20	−90.3	767	538	3.6
21	−99.0	814	394	4.3
22	−130.0	788	389	4.1

1. Corresponds to cross sections labeled in Fig. 1.
2. Refers to the leading parameter of equations (1) and (3).

possible correlation between the expected elevation and variance. The standard deviation of the elevations based on the mean sum of square errors is ±12 feet.

The twenty two cross sections listed in Table 2 and labeled in Fig. 1 reflect the benefits of the mathematical analysis. For some of the buried valleys, cross sections could not be obtained because the wells did not lie in a straight line or there were not enough wells in the area. Using the available cross sections and certain wells, the slope of the ancient Wisconsin River was found to be 1.6 ± 0.1 feet/mile and that of the ancient Wolf River, 1.8 ± 0.8 feet/mile. Furthermore, the results listed in Table 2 show that the depths of the glacier induced channels are approximately 200 feet deep. In one case, for instance, cross sections 13 and 14 reveal the existence at Montello of a 520 foot deep, 1 mile wide channel which as it exists today drops 35 feet in 0.5 miles.

In addition to the results of the mathematical analysis, information from several wells proved to have been particularly important in locating the buried valleys and it is tabulated below (Table 3).

TECHNIQUES USED IN CONSTRUCTING THE MAPS

Information obtained from well constructor's reports provided most of the data used in constructing the map of the preglacial river valleys and the topographic map of the bedrock. The location, annotated with the depth of bedrock, of each well was plotted on graph paper at a scale of 1 mile to a half inch. Centered at the location of the deepest wells, a circle was inscribed having a radius such that the circumference equaled

TABLE 3. Important Wells

Location T.N.-R.E.-Sec.	*Owner*	*Material at bottom*	*Elevation of bottom above sea level*
14-8-25	Endeavor Farms	SS[1]	485 feet
14-9-21	Turner	SS	552
14-10-11[2]		SS	575
15-8-17[2]	Creamery	SS	610
15-9-21	Vanearn	Granite	488
15-9-34	Preuss	Sand	436
15-10-6	Quinn	SS	558
15-10-16	Hauserman	Granite	485
15-10-36	Lettuce Cooling Plant	Granite	490
15-11-22	Klawitter	SS	420
15-11-30	Tidd	SS	717
16-8-15[2]	L. Kruger	Granite	512
16-9-25	Shimpack	Granite	485
17-11-4	Doiro	SS	462
17-13-6	Berlin Conservation Club	SS	473
18-11-34	Bartol	Clay	486
18-13-22[2]		SS	475

1. SS = Sandstone
2. Obtained from Alden (1918), otherwise obtained from DNR well constructor's reports.

the contour level of 700 feet. In effect, each of these wells was placed at the bottom of an imaginary bowl whose rim stood at 700 feet above sea level and whose bottom equaled the depth of the well. The radius of the bowl was obtained from the mathematical model in the following way. In those special cases where three wells fell in a straight line while spanning a valley, the shape of that cross section was estimated according to the procedure described earlier. The parameter a and the parameter c of all the cross sections were averaged together and the result served to describe a typical cross section. Knowing the depth of a well and height of the rim, in this case 700 feet, the radius was found by using equations (1)–(3) with the averaged parameters. The radius found in this manner can not account for the variability from one valley to another, nonetheless, following the path of the overlapping circles traced out a rough picture of where the preglacial river valleys existed.

Wells lying in the vicinity of the valleys were used in a triangulation method to locate as accurately as possible the bottom of a valley. Before taking that step, however, it was necessary to estimate the slopes of the ancient Wisconsin and Wolf river beds. Employing the method of least squares, estimates of the slopes were obtained based on the cross sections and wells marked in Fig. 1. Knowing the elevation of the river bottom at any point along a valley and the elevation of the bottom of a well lying on a valley's fringe, the distance of a well from the bottom of a valley was found by again using the model this time with the parameters associated with the cross section nearest to the well. From these wells an arc was swung with a radius corresponding to that distance which the valley's bottom was supposed to lie from a given well. Three intersecting arcs give a fix for the location of the bottom of a valley. Two intersecting or almost intersecting arcs were also used, if they were on opposite sides of a valley. And as a final resort, usually to compensate for gaps that sometimes occurred in the mapping of the valleys especially in the towns of Neshkoro and

Seneca, a single arc was used to reckon a position of where the bottom of a valley ought to be. Based upon the fixes, the midpoints of the valley cross sections, and the locations of certain wells that happened to reach the bottom of a valley, the locations of the preglacial river valleys were ascertained. The result was translated to the pertinent section of the Wisconsin Department of Transportation 1984 District Highway Map.

The method of contouring could have been used to accomplish the same end instead of the triangulation method that was actually employed. The contouring that was done is shown in the topographic map of the bedrock (Fig. 2). The levels were drawn freehand so that the accuracy of the levels is only about ±100 feet, whereas the accuracy of the elevations based on the mathematical model is ±12 feet. Because of that greater degree of accuracy, the method of triangulation was adopted for use in making the map of the preglacial river valleys. Once the map was made, approximately half of the mapping was field checked as time permitted. The map was also checked against aerial photographs and USGS topographic maps. In general, it was found that the wetlands in these three counties lie in the remnants of the ancient valleys.

The technique used in constructing the map of the glacier's movement was already explained earlier in the section pertaining to the discussion of the data.

Influence of the Precambrian Bedrock

To what degree the Precambrian bedrock influenced the courses of the ancient rivers and the glacier's movement in this region is largely a matter of conjecture. The Precambrian bedrock that underlies the sandstone and limestone is composed of granite and rhyolite. These igneous rocks were formed 1.765 billion years ago during a period of volcanic activity occurring to the northwest of Marquette County (Smith, 1978b). In subsequent ages, the sedimentary rocks of sandstone and limestone were formed on top of the Precambrian rock as a result of successive cycles of sedimentation associated with advancing and retreating seas (USGS, 1976). In a few instances, the Precambrian bedrock protrudes to the surface and is exposed as granite at Montello and Red Granite and the rhyolite of Observatory Hill in Marquette County and at Endeavor. Whereas the rhyolite forms the Precambrian bedrock in southeastern Marquette and Green Lake Counties, granite constitutes the bedrock in the northwestern section of the counties. The boundary between the two types of rocks bears 50° east of north (Smith, 1978b), and is essentially perpendicular to the direction of flow of the molten rock. The dashed line labeled T in Fig. 8

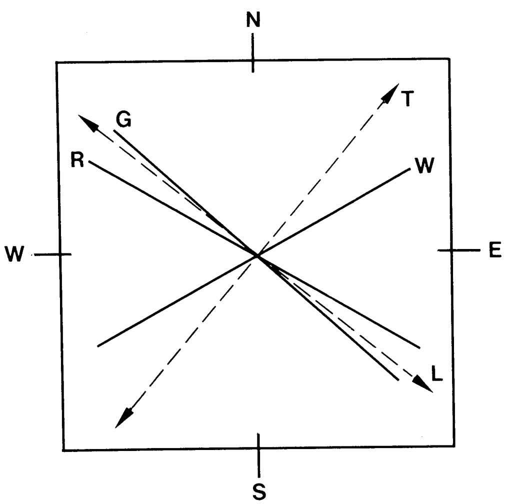


Fig. 8. Relation between aspects of the Precambrian bedrock and the direction of the glacier's movement and the courses of ancient rivers.

T = Axis of the contact between granite and rhyolite (Smith, 1978b).
L = Axis of the direction of flow of the molten igneous rock (Adopted from Smith, 1978b).
G = Direction of movement of the glacier in Marquette and most of Green Lake Counties.
R = Course of the ancient Grand River.
W = Course of the abandoned south branch of the ancient Wisconsin River.

The close associations of T and W and of L, G, and R suggest that the Precambrian bedrock influenced the courses of preglacial rivers and the glacier's direction of movement in Marquette and Green Lake Counties.

shows the direction of the contact between the granite and rhyolite, the granite being to the left and the rhyolite to the right. The dashed line labeled L in the same figure shows the direction of flow of the molten rock. The direction of the glacier's movement, G, and the course of the ancient Grand River, R, lie very close to L and appear to be correlated with the direction of flow of the molten rock. Also the course of the abandoned southern branch of the ancient Wisconsin River, W, seems to be correlated with the contact between the granite and rhyolite, T. Although the topography of the Precambrian bedrock is unknown, it appears from Fig. 8 that the bedrock affected the courses of preglacial rivers and the glacier's movement in this area.

Summary

Evidence suggests that the Precambrian bedrock played a role in determining the courses of the ancient rivers and the direction of the glacier's movement. Prior to glaciation, the physical geography was dominated in this region by the Wisconsin, Wolf, and Fox Rivers that had flowed through a country which would be unfamiliar to anyone living today. Glaciation radically altered the preglacial landscape. The thick layer of sand which is found in these counties came from the pulverizing action of the glacier on the sandstone. The lacustrine deposits left behind by the retreating glacier helped to create the many and extensive wetlands remarkable to this region. Marquette County, in 1938, had the greatest proportion, 29%, of wetlands to its size of any county in the state (WCD, 1963).

The eight drainage channels associated with the successive damming of the ancient Wisconsin River were created by the advance of the Green Bay Lobe through Green Lake and Marquette Counties during the Wisconsin stage of Pleistocene glaciations. The network of buried valleys was discovered primarily by means of well constructor's reports and mapped with the aid of a mathematical model that was designed to describe a hypothetical valley cross section. All of the preglacial river valleys in these counties are buried as a result of glaciation. What once were deep river valleys are now hidden. Only the muck farms and wetlands most visibly mark the locations of those valleys today.

Acknowledgements

Helpful comments for improving the quality of the manuscript were given to me by Lee Clayton of the Wisconsin Geological and Natural History Survey, Esta Lewin, David Mickelson of the University of Wisconsin–Madison Geology Department, and Mary Zellmer. I want to thank Christine Reinhard, Assistant Wisconsin State Cartographer, for her very helpful suggestions for making the illustrations.

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SPATIAL ATTRIBUTES OF UW UNDERGRADUATE ATTENDANCE PATTERNS

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Abstract

At first glance, the attendance pattern of undergraduates in the UW system appears to be very complex. It is often assumed that socioeconomic variables such as income and education are the major causal factors involved, but these do very little to "explain" UW undergraduate attendance patterns. A simple model based on distance (and variations thereof) yields much better results. Such a model can account for a very large percentage of the variation in undergraduate attendance patterns for individual campuses and most of the anomalies that remain are easily explained. This unconventional explanation of attendance patterns can be extended to consider the "locational efficiency" of campuses and programs.

INTRODUCTION

More than 100,000 residents of Wisconsin are enrolled as undergraduates at the thirteen four-year campuses of the UW System, but why does an undergraduate from a given county choose a specific campus? Many explanations could be offered. When individual undergraduates are polled, they cite the amount of financial aid available, the presence of specialized programs, family/friendship ties, the academic reputation of a campus or department, or reasons as trivial as the "party" reputation of a campus or the male/female ratio. Initial career decisions certainly play a role. A beginning undergraduate from Green Bay, for example, who wants to major in industrial arts, nursing, engineering, or agriculture has a more limited choice of potential campuses than one who intends to major in mathematics. On the other hand, most campuses offer "pre" programs (pre-engineering, pre-med, etc.) and many, if not most, undergraduates enter their college career undecided and often change their major more than once. Many select their field of study because a single course, taken to meet general education requirements, gets them interested in a major which may not be available on all campuses. These individuals did not choose a particular campus initially because it offered their eventual major. Had they begun their academic career at another campus, they might have selected another field of study.

We cannot predict with unerring accuracy the UW campus that will be chosen by a given Joe/Jane Freshman from a given place in the state. There may be as many reasons as there are individual undergraduates, but a consideration of student origins raises an interesting set of questions. Is there a general model which can predict attendance patterns at UW campuses with a high degree of accuracy? Is the location of UW campuses "equitable" or "efficient" given the population distribution of the state? Could a consideration of important variables and geographic patterns be used to make better decisions about the location of future facilities and programs or the termination of others? In this study, only undergraduates from Wisconsin enrolled in the Fall Semester of 1983 at the thirteen four-year campuses are considered.

CORRELATION WITH POPULATION

Common sense suggests that the number of UW undergraduates from a given county

TABLE 1. Partial correlation results.

Campus	1980 Population[a]	Controlling for: Median Family Income[b]	Education Level[c]	Both[d]
UW-TOTAL	0.973	0.966	0.980	0.981
MSN	0.217	0.045	0.036	−0.007
MIL	0.796	0.736	0.764	0.744
EAU	−0.205	−0.028	−0.151	−0.056
GBY	−0.023	−0.039	0.046	0.004
LAC	−0.125	−0.056	−0.097	−0.062
OSH	−0.013	−0.095	0.032	−0.046
PKS	0.118	−0.010	0.121	0.034
PLT	−0.113	−0.076	−0.089	−0.075
RVF	−0.137	−0.103	−0.170	−0.130
SPT	−0.139	−0.076	−0.087	−0.067
STO	−0.020	−0.057	−0.176	−0.092
SUP	−0.101	0.007	−0.093	−0.024
WTW	−0.116	−0.085	0.064	−0.052

[a] r_{12}, where 1 = # of UW undergraduates at campus from each county and 2 = 1980 population.
[b] $r_{12.3}$, where 3 = 1980 median family income for each county.
[c] $r_{12.4}$, where 4 = per cent of county population with more than 16 years of education.
[d] $r_{12.34}$
Source (demographic data): 1980 Census of Population.

should be strongly correlated with the population of the county. The greater the population, the greater the number of undergraduates. Within this general trend, however, there might be other factors causing counties with similar populations to send different numbers of undergraduates to the UW System. Secondary variables which immediately come to mind are income and education. The assumption is that counties with higher incomes and educational levels will send a higher proportion of their population on to college. Simple and partial correlation coefficients were calculated to test this hypothesis and are given in Table 1.

For *total* UW undergraduates, the correlation between the number of undergraduates from a county and its population is very high ($r = 0.973$). The relationship is positive, i.e., as population increases, the number of undergraduates also increases. In partial correlation, one or more variables can be "held constant" to examine the relationship between variables without the intrusion of other factors. If income and education are important, the correlation with population should decline when they are considered, but the partial correlation coefficients in Table 1 show that controlling for income and educational levels (both individually and collectively) produces almost no change in the relationship between the total number of UW undergraduates from a county and its population. The individual campuses listed in Table 1, however, show very different results. *Positive* relationships are found only for the Madison, Milwaukee, and Parkside campuses. For the other campuses, the relationship is *negative* indicating that as population increases, the number of undergraduates from a county to that campus *decreases*. In addition, with the exception of Milwaukee, the correlation with population is rather weak and controlling for income and educational levels reduces it even more. There is a very high correlation in Wisconsin between population and income/education. The counties with the largest populations (urban counties) also have the highest incomes and the highest educational levels.

Madison, Milwaukee, and Parkside are located in the densest urban cluster of the state, hence the positive correlation with population (and education/income). The outstate campuses are distant from the concentration of population and controlling for education and income does little to overcome this distance handicap.

Campus Capture Areas

Within the context of the "Wisconsin Idea," campuses were established over the state to provide greater accessibility to higher education for all citizens. This suggests that each campus serves its "regional" market which could account for a large amount of the variation in the origin pattern of its undergraduates. Like other types of market areas, these should reflect the "attraction" or drawing power of individual campuses. The ability of a campus to attract students was assumed to be its "theoretical target capacity." These targets are given in a 1976 in-house UW System study which recommended potential enrollment limits for each campus (UW System, 1976). Target capacities were based on physical facilities and faculty/staff sizes and are directly proportional to enrollments which existed in the late 1970's. Enrollment itself, of course, could be used as a surrogate for "drawing power" because enrollments reflect physical capacities and availability of programs and majors. System targets, however, were assumed to reflect a more consistent estimate of drawing power. How can the boundary between two competing campuses be drawn? In this study, the "breaking point" between campus pairs was based on the following model:

$$BP_{xy} = \frac{D_{xy}}{1 + \sqrt{C_y/C_x}},$$

where: BP_{xy} = the "breaking point" between campus x and campus y.
D_{xy} = the distance between x and y.
C_xC_y = the target capacities of x and y.

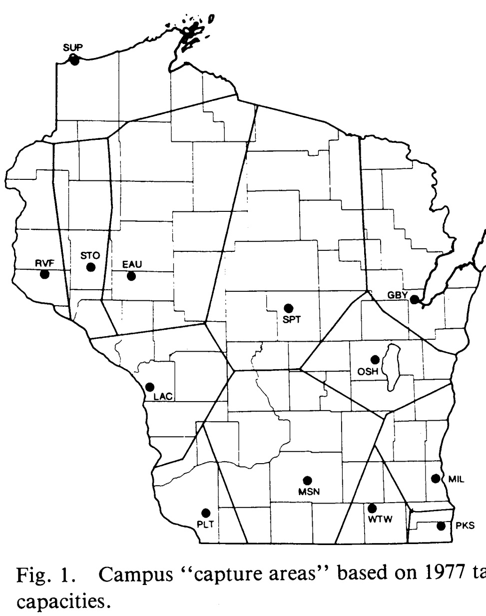

Fig. 1. Campus "capture areas" based on 1977 target capacities.

If two competing campuses have the same enrollment capacities, the "breaking point" will occur exactly half-way between them. A larger capacity, however, shifts the breaking point toward the smaller campus and expands the capture areas of larger campuses at the expense of their smaller competitors. The market areas in Figure 1 were derived by applying the above formula between each campus and its nearest competitors to determine breaking points. A straight line was drawn from a campus to its competitors and a perpendicular line was then extended from each breaking point. The connection of the perpendicular lines produces the "capture area" polygons.

How well do empirical attendance patterns match these theoretical capture areas? Actual capture patterns cannot be accurately mapped with the *raw number* of undergraduates from each county to each campus. A county with a large population like Milwaukee may send a greater number of undergraduates to a campus than a smaller county. The number from Milwaukee, however, can be a very small percentage of the total UW undergraduates from Milwaukee. The absolute number of undergraduates from Milwaukee at a campus is large, but the campus "captures" a relatively small percentage of the Milwaukee's undergraduate population. For example, Milwaukee sent 417 undergrtaduates to UW-Eau Claire in Fall 1983 and was the fourth leading county in terms of the raw number of undergraduates at Eau Claire. This total, however, represented less than two per cent of the total UW undergraduates from Milwaukee County. Using the *percentage of total UW System undergraduates* captured by a given campus from each county gives much more comparable estimates of capture rates. These percentages were used to derive the "actual" capture areas shown in Figure 2. The isopleths were based on the campus which "captured" the greatest percentage of total UW undergraduates from a county. Where capture rates in a county were almost the same for two campuses, the lines were interpolated based on the magnitudes of the competing capture rates.

Actual "capture areas" generally follow the theoretical patterns developed in Figure 1, but there are several exceptions. Stout's actual capture area is much smaller than its theoretical while Eau Claire's is larger. Madison's actual capture area extends into Sheboygan and Manitowoc counties at the expense of UW-Oshkosh. Madison is also the dominant campus in Marathon County and is the only example of an "enclave" within the capture area of another campus. This is not surprising given its size, status, and location, but in all three counties (Manitowoc, Sheboygan, and Marathon), UW-Center campuses capture almost twice as many UW undergraduates as any four-year campus. For most campuses, however, there is a remarkable similarity between actual and theoretical capture areas.

Capture percentages vary considerably among campuses. For example, UW-Parkside captures sixty-five per cent of all UW undergraduates from Kenosha County, but attracts zero undergraduates from many distant counties. Madison captures eighty-two per cent of all UW undergraduates from Dane County and some undergraduates from every county in the state. Capture rates in home counties varies from a high of eighty-six per cent for UW-Superior to a low of forty-seven for UW-Green Bay.

The Distance/Intervening Opportunities Model

The pattern presented in Figure 2 suggests two "hidden" explanations of UW attendance patterns. They are hidden in the sense that they are rarely (if ever) mentioned as explanatory variables yet are capable of predicting the capture pattern with high degree of accuracy. First, capture rates are an *inverse* function of distance: the greater the distance, the lower the capture rate for a given campus. Distances used in this study were measured between county centers. Secondly, the amount of competition or "intervening opportunity" in a specific direction plays a very important role. For example,

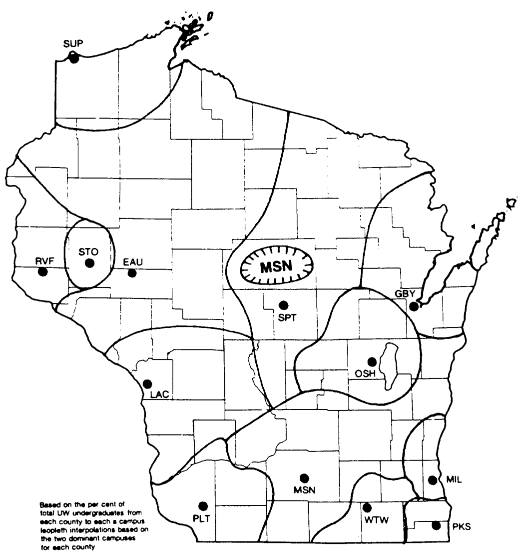

Fig. 2. Actual campus "capture areas."

Eau Claire's capture area extends a much greater distance to the northeast where there is little competition than due west where there is considerable competition from UW-Stout. The relationship between capture rates and intervening opportunity should also be inverse. For a given campus, intervening opportunity ("competition") was measured by:

$$IO_{xy} = (D_{xy} - D_{cy}) + D_{xy},$$

where: IO_{xy} = intervening opportunities between campus x and county y.
D_{xy} = distance between campus x and county y.
D_{cy} = distance to the UW campus *closest* to county y.

For the home county of each campus, of course, the value of IO equals zero [IO = (0-0) + 0]. The value of IO, however, between a given campus and a county which has another UW campus is *twice* the value of the distance between county centers. For example, if the distance between two counties is thirty miles and each has a UW campus, the value of intervening opportunities is sixty [IO = (30 − 0) + 30]. This effect is used as a surrogate for competition. Both hypotheses can be tested with simple correlation.

A visual inspection of distance (X) and capture percentages (Y) scattergrams indicated that the form of the relationship was not linear. Capture rates decreased with increases in both simple distance and intervening opportunities, but *at a decreasing rate.* This effect was adjusted for by using both the square root and common log of each. Correlation coefficients are shown in Table 2. Both distance and intervening opportunity values (unconverted) produce statistically significant (.0001 level) results. All signs are *negative* as hypothesized indicating that as distance (or intervening opportunity) increases, the rate of capture *decreases.* In all cases, converting the independent variables to square root and common logs yields higher correlations than raw values and, in most cases, the square root gives slightly better results than conversion to common logs. Coefficients of determination (squares of correlation coefficients) are a measure of the per cent of variation in the dependent variable (capture rates) which is "explained" by

TABLE 2. Simple correlation coefficients.*

	DIST	$\sqrt{DIST}$	*LOG (DIST)*	*IO*	$\sqrt{IO}$	*LOG (IO)*
MSN	−0.619	−0.734	−0.666	−0.650	−0.758	−0.730
MIL	−0.468	−0.621	−0.564	−0.465	−0.624	−0.635
EAU	−0.720	−0.803	−0.751	−0.734	−0.832	−0.825
GBY	−0.541	−0.654	−0.606	−0.537	−0.663	−0.674
LAC	−0.649	−0.778	−0.731	−0.658	−0.794	−0.797
OSH	−0.668	−0.790	−0.760	−0.668	−0.804	−0.823
PKS	−0.338**	−0.504	−0.479	−0.325	−0.494	−0.552
PLT	−0.577	−0.713	−0.835	−0.611	−0.749	−0.878
RVF	−0.567	−0.680	−0.812	−0.568	−0.682	−0.829
SPT	−0.622	−0.744	−0.629	−0.666	−0.748	−0.733
STO	−0.614	−0.732	−0.625	−0.616	−0.735	−0.698
SUP	−0.531	−0.698	−0.632	−0.503	−0.659	−0.660
WTW	−0.613	−0.720	−0.698	−0.625	−0.749	−0.788

DIST = distance (measured between centers of counties).
IO = intervening opportunities as defined in text.
* All coefficients significant at the 0.0001 level unless noted.
** Significant at 0.002 level.

variation in the dependent variable. The best predictor for each campus yields "explanation" rates which range from a low of about twenty-five per cent for Parkside (square root of distance) to a high of seventy-seven percent for Platteville (log of intervening opportunities). The statistical results indicate that distance (and its variation, intervening opportunities) is a very important variable in determing UW attendance patterns.

Once again, income and education levels were added to see if the predictive power of the model could be improved; if income and education are the important variables, the correlation with distance should decline when they are considered. Results are shown in Table 3. In general, correlations between student origins and distance remained remarkably constant when the effects of income and educational levels were added. The two exceptions to this generalization are Milwaukee and Parkside. For both, the correlation with distance drops appreciably when controlling for the effects of income and income and education combined. These two campuses are different from the other campuses in the System in that commuters are much more important than a residential student population. The daily driving distance limit of each "commuter shed" is very small and, beyond this limit, other factors take over. Parkside gets 92 per cent of its Wisconsin undergraduates from Racine and Kenosha Counties while Milwaukee gets 84 per cent from Milwaukee and Waukesha Counties. Only Green Bay and Superior come close to these levels from their home county (both 65%). Most of the other campuses hover around 25 per cent. The overwhelming importance of close student populations for these four campuses is supported by Table 3. The greater the importance of the "home" counties, the lower the simple correlation with distance. When variations in potential undergraduate populations are factored out by using percentage (of total

TABLE 3. Partial correlation results* undergraduates with distance.

		Controlling for		
Campus	*Distance*[a]	*Median Family Income*[b]	*Education Level*[c]	*Both*[d]
MSN	−0.619	−0.528	−0.591	−0.603
MIL	−0.468	−0.027[1]	−0.420	−0.238[2]
EAU	−0.720	−0.657	−0.711	−0.650
GBY	−0.541	−0.574	−0.544	−0.545
LAC	−0.648	−0.637	−0.646	−0.637
OSH	−0.668	−0.681	0.676	−0.652
PKS	−0.338[3]	−0.216[4]	−0.354[5]	−0.159[6]
PLT	−0.577	−0.624	−0.591	−0.624
RVF	−0.576	−0.613	−0.603	−0.609
SPT	−0.622	−0.644	−0.624	−0.651
STO	−0.614	−0.550	−0.609	−0.534
SUP	−0.531	−0.520	−0.538	−0.505
WTW	−0.613	−0.508	−0.604	−0.486

* All coefficients significant at the 0.0001 level unless noted.
Significance levels: [1]0.0043 [2]0.0024 [3]0.002 [4]0.036 [5]0.002 [6]0.096

[a] r_{12}, where 1 = per cent of UW undergraduates at a campus from each county and 2 = raw distance measured between county centers.

[b] $r_{12.3}$, where 3 = 1980 median family income.

[c] $r_{12.4}$, where 4 = per cent of county population with more than 16 years of education. (1980).

[d] $r_{12.34}$

Source: 1980 Census of Population.

UW undergraduates) capture rates, distance accounts for a very large proportion of the total variation in attendance patterns. Adjusting for income and educational levels (via partial correlation) does little to improve the accuracy of prediction. The distance/intervening opportunity model "explains" the UW undergraduate attendance pattern with a high degree of accuracy.

Residuals from Regression

What factors account for the variation not "explained" by distance and its variations? Some understanding can be gained by considering the residuals from regression which fall outside one standard error of estimate. When positive and negative residuals are mapped, it is immediately apparent that two different factors are involved. UW-Eau Claire is used as an example with residuals greater than one standard error of estmiate shown in Table 4. Competing campuses account for most of the counties for which the model *overpredicts* the capture rate by more than one standard error. For Eau Claire, the negative counties either contain a competing campus or are contiguous to one with the lone exception of Marquette County (equidistant between MSN and SPT). This explanation of negative residuals also holds true for all other UW campuses.

Three of the positive residuals (model *underpredicts* the capture rate) are in Eau Claire's capture area. This is also the general rule for all campuses. Two of the remaining positive residual counties (Burnett and Ashland) are fairly close. Only Door County is difficult to understand. The positive residual counties are also a mixed bag for other campuses as well. Some have high income levels and some low. Some have high educational levels while others are well below the state average. Some are rural and others urban. These anomaly counties seem to be the result of "random" factors. Friendship/kinship ties may very well play an important role. Certain high schools seem to be better represented at Eau Claire, for

Table 4. Residuals from regression.[1] UWEC capture rates and distance.[2]

Negative County Residuals		*Positive County Residuals*	
Counties with UW Campus		*In UW-Eau Claire "Capture" Area*	
Douglas	−1.0071	Chippewa	+2.5437
Dunn	−1.5890	Eau Claire	+2.7411
Grant	−1.0556	Rusk	+1.4386
La Crosse	−2.4686	Taylor	+1.6693
Pierce	−2.2689	*Other*	
Portage	−1.6156	Ashland	+1.3380
Counties Contiguous to UW Campus County		Burnett	+1.3901
Adams	−1.3380	Door	+1.0986
Crawford	−1.4282		
Richland	−1.1316		
St. Croix	−1.1334		
Wood	−1.0243		
Vernon	−1,1262		
Other			
Marquette	−1.2391		

[1] Greater than one standard error of estimate (8.76017).

[2] For Y = a + bX, where Y = UW-Eau Claire undergraduates from county as a per cent of total UW undergraduates from county.

X = square root of distance of county from Eau Claire (measured between county centers).

a = 57.02226, b = 24.76499, r = 0.803.

example, than others in the same distant county. Once a few undergraduates from a high school or small town go to a particular campus and have success there, the process may snowball so that the tradition of undergraduates from Place X attending Campus Y is carried on through time. Capture rates (per cent of total UW undergraduates) are so low in distant counties that only a few undergraduates one way or the other can throw a county outside the limits of one standard error of estimate. In distant counties, alumni who are high school guidance counselors or coaches or the experiences of siblings and parents may also be critical.

Locational Efficiency

The role that distance plays in determining UW enrollment patterns, raises the question of the "locational efficiency" of the respective campuses. One way to consider this is to map the centers of the undergraduate populations for each campus (Figure 3). The center of population for all UW undergraduates is remarkably close to the center of the total population of the state as would be expected from the simple correlation coefficient for this relationship. For individual campuses, however, undergraduate population centers are shifted away from the campus locations toward the total population center. The degree of displacement varies from campus to campus. Milwaukee, Parkside, Whitewater, and Madison are shifted the least, while Stout, Eau Claire, La Crosse, and River Falls are shifted the most. Generally, the closer a campus is to the major population concentration of the state, the less the shift of its undergraduate population center and vice versa. In Figure 3, the closeness of the center of total UW undergraduates to the population center of the state would seem to indicate that the campuses are well located to serve the population of the state, but this idea is less credible when individual campuses are considered. The amount of spatial displacement of the smaller UW campuses is somewhat a function of the degree of specialization. For example, UW-Stout, with its very specialized programs, is more displaced toward the center of state population than is UW-Eau Claire. The more specialized the campus, the more it should draw its undergraduates from the entire state as opposed to more "general" campuses. Stout has the "poorest"

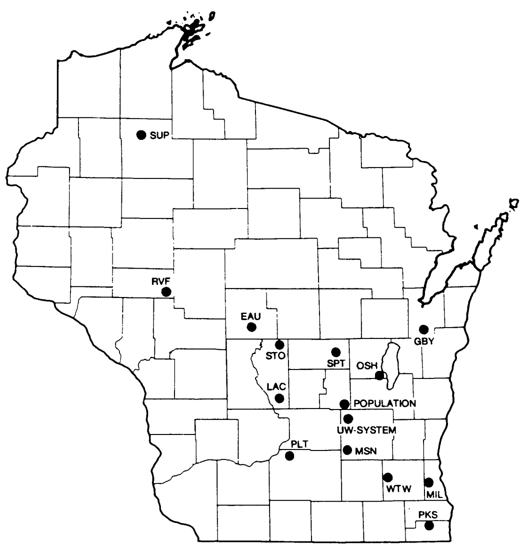

Fig. 3. Mean centers of campus populations.

Table 5. Theoretical and actual capture rates.

Campus	*Per Cent of State Population in Theoretical Capture Area*	*Per Cent of Total UW-System Undergraduate Enrollment*
MSN	13.80	23.67
MIL	33.04	18.86
EAU	5.60	8.27
GBY	7.58	3.69
LAC	4.16	6.36
OSH	9.05	8.06
PKS	4.45	4.08
PLT	1.93	4.21
RVF	2.16	2.62
SPT	8.97	6.67
STO	2.57	4.08
SUP	1.94	1.20
WTW	4.75	7.50

location of all campuses in this respect. Another simple way to consider locational efficiency is to compare the proportion of the state's population in the theoretical capture areas of Figure 1 with the proportion of the total UW undergraduate populations actually captured by each campus. This is done in Table 5. Madison captures a proportion of the total UW undergraduate student body which is almost twice the proportion of the state's population found in its theoretical capture area. This is to be expected from the "flagship" campus of the System. UW-Milwaukee, on the other hand, has an enrollment "capacity" which is half that of its tributary population. The creation of UW-Parkside seems to have been an "efficient" action in that it captures almost exactly its theoretical tributary area and "soaks up" an excess population that would otherwise seek to go to the already "saturated" campuses of Madison, Milwaukee, or Whitewater. The equitability of Parkside is also demonstrated by the small displacement of its mean student center from its actual location (Figure 3). Both Superior and River Falls face the stiff competition from nearby Minnesota campuses with reciprocal tuition rates (UM-Duluth and the University of Minnesota) and each just captures its expected share of the state's undergraduates as estimated by market areas.

Specialized programs should be located so as to serve their target populations best. To accomplish this, the target population must be carefully identified. For example, agricultural or veterinary science programs may serve agricultural concentrations rather than the general population. Agricultural programs are required at Madison of course because it is the land grant institution, but consider the "secondary" agricultural campus of River Falls. How well is it located with respect to the state's agriculture? The per cent of total county land in agriculture was used as a surrogate for agricultural activity in the state. This measure factors down the importance of counties with little agricultural activity such as Milwaukee or Forest. The mean center of this distribution is in southern Adams County, which suggests that Stevens Point would be a "better" location for such programs. Of course, other factors, such as economies of scale and existing facilities, must also play a role and are usually considered by decision makers.

Conclusions

In conclusion, the attendance pattern of the UW-System campuses is, at first glance, complex and would seem to require an intricate and complicated system of equations to unravel the puzzle. The simple geographic variable of distance, however, can be used to predict most of the variation in the pattern with a high degree of accuracy. This study highlights the utility of the geographic approach. Most of the data summarized in this study are usually considered only in tabular form by the gnomes of Van Hise Hall and it is very rare to see any policy statement from System Administration which contains a map or considers the geographical ramifications of decisions. Both the efficiency and equitability of such decisions might be improved by such considerations.

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LAND CHARACTERISTICS ASSOCIATED WITH DIVERSE HUMAN HEART AND DIGESTIVE SYSTEM CANCER DEATH RATES AMONG WISCONSIN COUNTIES

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Abstract

Among Wisconsin counties, the highly diverse land characteristics, such as northern and central sandy soils, silty and clayey soils, shallow glacial till depth to bedrock, and the industrialized areas are associated with diverse age-adjusted human heart death rates (HDR) and digestive system cancer death rates (CDR) per 100,000 persons per year, as reported by the Wisconsin Division of Health. For Wisconsin, the mean for HDR is 321 ± 33 and for CDR is 38.4 ± 4.5, an eight-fold difference. Maps of Wisconsin were prepared with HDR and CDR in each county on a whole-life basis. The 15 counties with the lowest HDR (less than 315) and CDR (less than 35) occur in the selenium-rich loessial silt along the Mississippi River (except where erosion has exposed bedrock sands). The 15 counties with the highest HDR (343 to 406) and CDR (42 to 52) are widely distributed among the land characteristics. Intermediate rates counties are similarly widely scattered. Recognition of the geographic diversity of HDR and CDR among Wisconsin counties may lead to hypotheses as to causation which will be helpful in further research.

INTRODUCTION

A commonly held view is that transportation of foodstuffs and migration of people should preclude, or obscure, any local effect of land characteristics on human nutrition or health differences among counties. Land variations such as soil sandiness, permeability, and other geographic land factors that affect food quality are, however, readily observable. Land low in selenium (Se) contents are indicated by low plant Se contents (below 50 ng g^{-1}) in many Wisconsin counties (Kubota et al., 1967). The need to supplement selenium (Se) in livestock feed to prevent cardiomyopathy ("white muscle disease") in Wisconsin is well-established (Hoekstra, 1974, 1975; Ullrey, 1974). Since crops do not need Se but take it up in the yield to the extent that is available, the Se deficiency in livestock is understandable. An inadequate remaining Se in the Wisconsin soil-plant-animal-human nutrition chain is possible (Jackson and Lim, 1982). Counties along north central Wisconsin and upper Michigan are shown in the "Atlas of Cancer Mortality of U.S. Counties, 1950-1969" (Mason et al., 1975) as having unusually high rates of stomach and other cancers. The land where this occurs in northern Wisconsin and upper Michigan is dominated by sandy soils developed in ancient quartzite rocks (Stose, 1960) and sandy till transported by several glaciations. The objective of this paper is to show that the age-adjusted

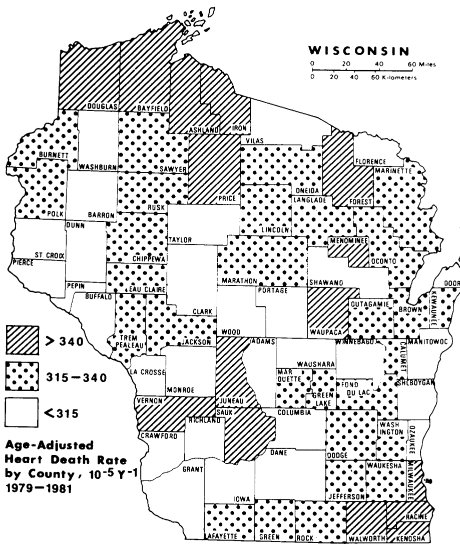

Fig. 1. Heart death rates in Wisconsin counties vary greatly, with a pattern related to land characteristics, being minimal in the deepest, loessial covered counties, but medium to high where erosion has exposed sandy strata in Trempealeau and Vernon counties, and in counties which are located in sandy glacial deposits.

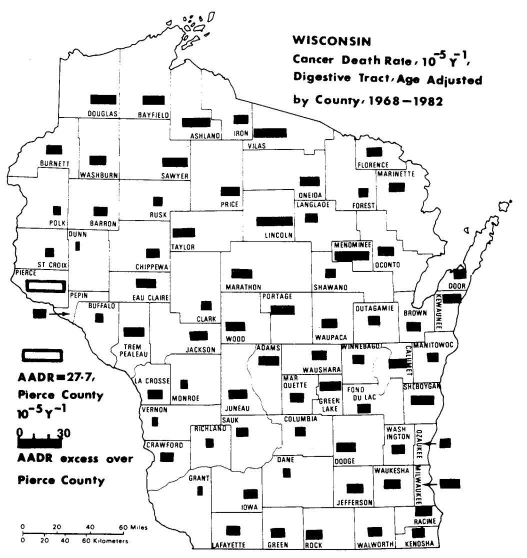

Fig. 2. Cancer death rates in Wisconsin counties vary greatly, with a pattern related to land characteristics, being minimal in highly loessial Pierce county and other deep-loess counties and up to twice as high in counties with sandy soils or intensively farmed silty land, eroded land, and land with shallow soils over bedrock.

TABLE 1. Mortality in Wisconsin counties from digestive tract cancers and from heart disease, age-adjusted per 100,000 persons per year.

County	*Stomach*	*Cancer deaths, 1968-1982* *Colo-rectal*	*Pancreas*	*Total*	*Heart disease deaths 1979-1981*
Adams	6.1	28.2	7.9	42.2	295
Ashland	11.1	27.3	8.8	47.2	363
Barron	7.5	21.8	8.2	37.5	272
Bayfield	5.9	29.4	7.6	43.0	374
Brown	6.7	23.2	7.4	37.3	321
Buffalo	6.9	19.8	6.7	33.4	295
Burnett	8.6	18.6	10.6	37.9	318
Calumet	6.1	24.8	8.5	39.5	345
Chippewa	6.6	21.8	8.7	37.1	320
Clark	6.9	21.2	6.2	34.2	273
Columbia	4.3	22.8	7.1	34.2	311
Crawford	6.6	20.0	9.7	36.4	283
Dane	5.8	19.4	7.2	32.3	266
Dodge	5.9	26.0	9.7	41.7	324
Door	10.2	17.8	9.1	37.1	265
Douglas	10.8	23.6	11.1	45.5	406
Dunn	6.1	16.6	8.6	31.4	284
Eau Claire	8.6	26.3	6.6	41.4	317
Florence	15.2	18.2	4.4	37.8	234
Fond du Lac	5.1	24.7	7.0	36.8	350
Forest	7.5	19.4	8.1	35.0	386
Grant	4.5	21.2	5.8	31.5	284

TABLE 1. Mortality in Wisconsin counties from digestive tract cancers and from heart disease, age-adjusted per 100,000 persons per year. (Continued)

County	*Stomach*	*Cancer deaths, 1968-1982* *Colo-rectal*	*Pancreas*	*Total*	*Heart disease deaths 1979-1981*
Green	7.7	22.6	6.6	36.8	326
Green Lake	6.6	28.6	7.3	42.4	316
Iowa	5.5	23.4	9.3	38.2	302
Iron	11.2	16.6	10.1	37.9	400
Jackson	7.6	23.5	9.2	40.3	318
Jefferson	5.8	24.2	8.2	38.2	317
Juneau	6.4	26.1	8.2	40.7	345
Kenosha	7.1	22.2	6.8	36.1	367
Kewaunee	8.6	24.6	7.1	40.4	336
La Crosse	5.9	23.2	8.4	37.5	286
Lafayette	7.2	21.6	8.2	37.0	326
Langlade	9.8	18.2	7.6	35.7	333
Lincoln	10.3	31.0	11.1	52.4	322
Manitowoc	5.3	22.9	7.7	35.9	309
Marathon	8.8	23.8	9.3	41.9	322
Marinette	7.8	22.8	8.0	38.6	333
Marquette	7.6	23.6	6.1	37.3	338
Menominee	8.2	33.5	10.0	51.8	399
Milwaukee	7.3	24.7	8.7	40.7	343
Monroe	6.4	19.1	7.5	33.0	312
Oconto	8.0	21.6	9.4	39.0	325
Oneida	5.8	25.2	11.1	42.1	323
Outagamie	6.2	21.3	8.2	35.8	324
Ozaukee	7.2	20.6	6.4	34.2	312
Pepin	7.1	22.7	6.3	36.1	313
Pierce	3.7	17.4	6.5	27.7	315
Polk	8.0	17.6	7.3	32.8	317
Portage	8.8	23.1	11.2	43.0	311
Price	8.1	24.6	7.6	40.3	362
Racine	7.6	20.9	10.0	38.5	344
Richland	6.3	19.1	7.3	32.7	274
Rock	6.6	23.3	8.9	38.7	330
Rusk	8.4	19.5	6.2	34.0	334
St. Croix	6.4	18.5	8.7	33.6	294
Sauk	6.1	20.5	10.0	36.6	370
Sawyer	8.6	25.6	10.7	45.0	319
Shawano	6.9	21.5	7.2	35.6	296
Sheboygan	7.8	25.9	9.1	42.7	259
Taylor	10.5	20.1	12.2	42.9	300
Trempealeau	7.8	26.6	7.8	42.2	317
Vernon	6.5	18.8	6.2	31.5	344
Vilas	9.5	29.7	10.3	49.5	297
Walworth	6.6	23.6	7.6	37.8	348
Washburn	8.6	22.0	8.2	38.7	298
Washington	7.5	22.0	7.2	36.7	316
Waukesha	7.8	22.9	8.3	36.7	325
Waupaca	5.9	23.7	8.8	39.0	381
Waushara	7.5	24.1	6.1	38.4	307
Winnebago	7.0	21.5	7.5	36.1	296
Wood	8.8	24.4	7.9	40.6	305
Wisconsin (State)	7.1	23.0	8.3	38.4 ± 4.5	321 ± 3

human heart death rate (HDR) and gastrointestinal cancer death rate (CDR), per 100,000 persons per year, varies among counties of Wisconsin, a cool temperature state. These studies were parallel to studies showing even wider variance of HDR and CDR in counties of the humid subtropical state of Florida (Jackson et al., 1985) and in regions of USA and China (China News Agency, 1985; Li and Jackson, 1985).

Methods

Because the human HDR and CDR are high in Wisconsin (as well as eastern USA, China, and elsewhere) the epidemiology for the years 1979 to 1981 for the HDR and 1968 to 1982 for CDR are presented on an age-adjusted rate per 100,000 persons per year in each Wisconsin county, as supplied by the Wisconsin Division of Health, Madison. The HDR rates were grouped into low, medium, and high rate groups and plotted. The CDR were considered as to increments over the rate in Pierce county (27.7 10^{-5} y^{-1}, the lowest rate in any Wisconsin county). Land characteristics, such as bedrock diversity, soil sandiness, erosion, fertility and suitability for intensive agriculture as mapped by the U.S. Geological Survey (Stose, 1960) and the Wisconsin Geological and Natural History Survey, Madison (Hole, 1976) were compared in an effort to interpret the great differences in HDR and CDR among Wisconsin counties.

Results

Land characteristics such as sandy soils, clay content, and glacial till depth to bedrock appear to be associated with different age-adjusted human whole-life heart death rates (HDR) and digestive system cancer death rates (CDR) per 100,000 persons per year (10^{-5} y^{-1}) among Wisconsin counties as mapped (Fig. 1 and 2). The annual age-adjusted HDR and CDR in Wisconsin are 321 ± 33 and 38.4 ± 4.5 10^{-5} y^{-1}, respectively (Table 1). The HDR varies from 234 in Florence county to 406 10^{-5} y^{-1} in Douglas county (173% greater in the latter) and the CDR range from 27.7 in Pierce county to 52.4 10^{-5} y^{-1} in Lincoln county (nearly a two-fold difference).

Heart death rate

To facilitate discussion of land characteristics in relation to human HDR, the age adjusted county rates were grouped as follows:

(1) Lowest rates, <315 . . . 29 counties,
(2) Intermediate rates, 315-340 . . . 28 counties,
(3) Highest rates, >340 . . . 15 counties.

The 29 counties which fall in the lowest HDR group are well-distributed throughout the state (Fig. 1). With the lowest county first: Florence, 234; Sheboygan, 259; Door, 265; Dane, 266; Barron, 272; and Richland, 274 10^{-5} y^{-1} are the six with the lowest HDR. Of these, only Sheboygan and Florence counties are in the high to medium CDR categories (Table 1, Fig. 2). The other four counties have silty and clayey soils which would be expected to be moderately well supplied with essential trace nutrient elements. The thick high-Se loess belt from Grant county north to St. Croix county has low HDR, except for those in which sandstone bedrock has been exposed by erosion. Vilas county with HDR 297 10^{-5} y^{-1} is noteworthy because the other northern acid, sand-rich counties are nearly all in the high HDR category. Infusion of trace elements has occurred by deep-seated mineralization of ore-bearing rocks (Mudrey et al., 1982), including copper, with which Se is associated. These rocks have been worked over by several glaciations.

Those 15 counties falling in the highest HDR group are, in decreasing order: Douglas, 406; Iron, 400; Menomenee, 399; Forest, 386; Waupaca, 381; Bayfield, 374; Sauk, 370; Kenosha, 367; Ashland, 363; Price, 362; Walworth, 348; Juneau, 345;

Racine, 344; Vernon, 344; and Milwaukee, 343 10^{-5} y^{-1}. Acid sandy land characterizes ten of these counties, including Juneau county. Kenosha, Racine, and Milwaukee are the most industrialized counties, with generally higher HDR risks. Vernon county has highly eroded land, induced by the erosiveness of the St. Peter sandstone caprock (Strose, 1960), even though it occurs in the deep loess belt. The land of Walworth county is high in glacial moraines and sandy outwash, and over half of it is intensively farmed.

Cancer death rates

To facilitate discussion of land characteristics in relation to variation in gastrointestinal cancer death rates (CDR) among Wisconsin counties, the counties were mapped (Fig. 2) in three age-adjusted CDR rates:

(1) Lowest CDR (28 to 35) . . . 15 counties,
(2) Intermediate CDR (36 to 41) . . . 42 counties,
(3) Highest CDR (42 to 52) . . . 15 counties.

Those 15 counties falling in the lowest CDR group are, in increasing order: Pierce, 27.7; Dunn, 31.4; Grant, 31.5; Vernon, 31.5; Dane, 32.3; Richland, 32.7; Polk, 32.8; Monroe, 33.0; Buffalo, 33.4; St. Croix, 33.6; Rusk, 34.0; Columbia, 34.2; Clark, 34.2; Ozaukee, 34.2; and Forest, 35.0 10^{-5} y^{-1}. The first ten counties occur in the portion of western Wisconsin in which loess (windblown silt) was deposited from the Mississippi flood plain during the Wisconsinan glacial age 14,000 to 16,000 years ago. This deposit came from the Cretaceous sea-bottom clays of Minnesota and South Dakota (U.S. National Research Council, 1952). Rusk, Columbia and Clark county soils received appreciable loess from various nearby glacial sources. Ozaukee county soils received shale clay pushed by glaciers from the Lake Michigan basin. Forest county soils received some glacial till from Ordovician dolomite and shales from the northeast and in addition lies near metal ore deposits intruded from below.

Those 15 Wisconsin counties falling in the highest CDR group are, in decreasing order: Lincoln, 52.4; Menominee, 51.8; Vilas, 49.5; Ashland, 47.2; Douglas, 45.5; Sawyer, 45.0; Bayfield, 43.0; Portage, 43.0; Taylor, 42.9; Sheboygan, 42.7; Green Lake, 42.4; Trempealeau, 42.2; Adams, 42.2; Oneida, 42.1; and Marathon 41.9. The agricultural lands of the 8 counties highest in CDR are predominantly covered by acid sandy soils developed in glacial outwash. Acid sandy soils predominate in the other counties of the group, except for Sheboygan and Marathon counties which have shallow silt over till and granite, respectively.

Medial heart and cancer death rate counties

The medium HDR and CDR counties are well-distributed throughout Wisconsin. The major fertilizer elements (phosphorus, potassium, and nitrogen) are routinely used to increase the yields of various crops. A rapid draw-down of trace elements in intensively cropped counties is inevitable, while acid sandy land is initially low in available trace elements. Zinc (Zn) is deficient in a majority of tests of sandy soils. For example, soil tests show 100% Zn deficiency for Lincoln county. Selenium (Se), which is not needed by plants, is taken up in the crop and the available supply drawn down in cropped land but not necessarily in forested counties.

A fairly low correlation ($r = 0.27$) between heart death rates (HDR) and digestive system cancer death rates (CDR) among the 72 Wisconsin counties suggests variation in causation. This situation contrasts greatly with that among the 67 Florida counties where a correlation, $r = 0.73$ ($p < 0.001$), occurs between HDR and CDR (Jackson et al., 1985). Because of the wide distribution in medial HDR and CDR counties in Wisconsin, the pattern of causation can only be fully explained by additional data on the geochemical and other locality characteristics of land and people.

Discussion

The soil-food-nutrition chain should carry adequate amounts of each of the 13 or so essential trace elements (Mertz, 1981). A well-established model is the role of iodine (I) supplementation in the prevention of human goiter in Wisconsin. An essential deoxidizing Se-enzyme (Hoekstra, 1974) helps prevent lipid oxidation in cell membranes and other cell-damaging oxidization reactions (Draper and Bird, 1984). Wisconsin is one of the high human HDR states (Li and Jackson, 1985). Few data have been gathered on human blood Se levels in various localities, even though heart deaths account for nearly half of all deaths (U.S. Department of Health and Human Services, 1974-1981).

Adequate Se is a chemopreventive anticarcinogen (Thompson, 1984). Active peroxides and epioxygen groups that promote cancer (Cerutti, 1985) are suppressed by Se enzymes and vitamin E (Hoekstra, 1975). Soils Se, as measured by plant uptake of Se, varied between localities within the states of Arizona, Arkansas, California, Missouri, Montana, and New Mexico; CDR varied inversely with the soil Se level within each state (Shamberger and Willis, 1971; Schrauzer et al., 1977). Ammonium molybdate application to soil lowered the incidence of human esophageal cancer in a low molybdenum area in China (Li et al., 1980). Cancer types have distinctive land distribution patterns among counties of China (Li et al., 1979), as found in Wisconsin. Trace element supplementation in human nutrition is available "over-the-counter," with expert dosage guidelines from the U.S. National Academy of Sciences (1980).

Conclusions

Diversity of land characteristics corresponds to a considerable extent with the wide HDR and CDR variations among Wisconsin counties. Status of essential trace elements such as Se and Mo show relationships to HDR and (or) CDR within regions of some states, between U.S. states, and between provinces of several countries. The diversity of human HDR and CDR among Wisconsin counties may come to be understood in terms of land (soil, water, and crops, dietary trace elements and toxic substances) with the accumulation of more data on localities.

Acknowledgments

This work was supported by the Academy of Sciences, P.R.C. and the College of Agricultural and Life Sciences, University of Wisconsin-Madison. Ji Z. Zhang and Chang S. Li are Honorary Fellows at the University of Wisconsin-Madison. Earlier, M. L. Jackson, The *Franklin Hiram King* Professor, was visiting scholar in China, sponsored by Academia Sinica. Special thanks are extended to Gregory Ruark for his assistance with the statistical analyses. Soil clay data were gathered with the assistance from the National Science Foundation grant EAR-8405422. Gratitude is expressed to Ms. Chrystie Jackson for her editorial and typing assistance.

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WISCONSIN'S ELECTRIC UTILITY INDUSTRY SINCE THE ENERGY CRISIS

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In the ten years following the Arab oil embargo of 1973-74, much upheaval and change occurred in the nation's electric utility industry. Foremost among the changes were rapid increases in electric rates, which induced conservation and a dramatic drop in the historical annual rise in electricity consumption. Between 1950 and 1973, electricity use grew an average of 8.2 percent every year, but between 1973 and 1982 the annual growth averaged only 2.3 percent [14]. The decline in consumption growth combined with the long lead times required to plan and construct new generation capacity left many utilities with overly ambitious and expensive expansion plans. The many canceled nuclear power plants in recent years exemplify this situation. Rapid increases in electric rates caused much consumer unrest, but rate increases did not prevent substantial deterioration of the financial condition of many electric utilities across the United States. Fuel and construction costs exacerbated by inflation and high interest rates grew faster than the revenues generated by the higher electric rates. The high rates, overly ambitious plans, poor utility finances, and the need to conserve energy have induced a variety of efforts to tighten regulation of utilities, improve public relations, and use innovative rate designs like time-of-day rates. The changes in the electric utility industry since the "energy crisis" of 1973-74 have been major, but more fundamental change during the 1980s and 1990s is probable.

National trends and statistics often mask variations within the nation. The purpose of this paper is to examine the status of the electric utility industry in Wisconsin, and in particular, to assess the extent to which national conditions have affected the state. The assessment is accomplished by comparing Wisconsin to the nation and to several neighboring states which compete with Wisconsin economically. These states, like Wisconsin, also obtain a majority of their electricity from coal. Variables relating to prices, consumption, and financial health are compared using two years, 1972 and 1982. (It should be noted that 1982 was a year of recession which would be reflected in this data). To assess patterns within Wisconsin, individual utility companies are compared, but data constraints limit this analysis to the major privately-owned utilities. This is not a major drawback because the privately-owned utilities serve approximately 83 percent of the state.

The literature concerning electricity contains several studies which examine the status of the electric utility industry. A recent Department of Energy study finds that the electric utility industry has not performed as well financially as other major industries [15]. Browne concludes that utilities have faced a difficult period since 1973, but problems are likely to continue because of uncertainty in demand growth and economic conditions [2]. Lastly, an argument that utilities are not planning enough generating capacity to meet long range needs (i.e. 15-20 years hence) because of regulatory constraints is made by Navarro [11]. These studies along with most of the related literature share the characteristic of being national in scope, but with the homogeneity of the national electric utility industry diminishing, it is increasingly essential to focus on smaller areas. This paper focuses on a smaller area by concentrating on a single state.

Another aspect of this paper relates to the

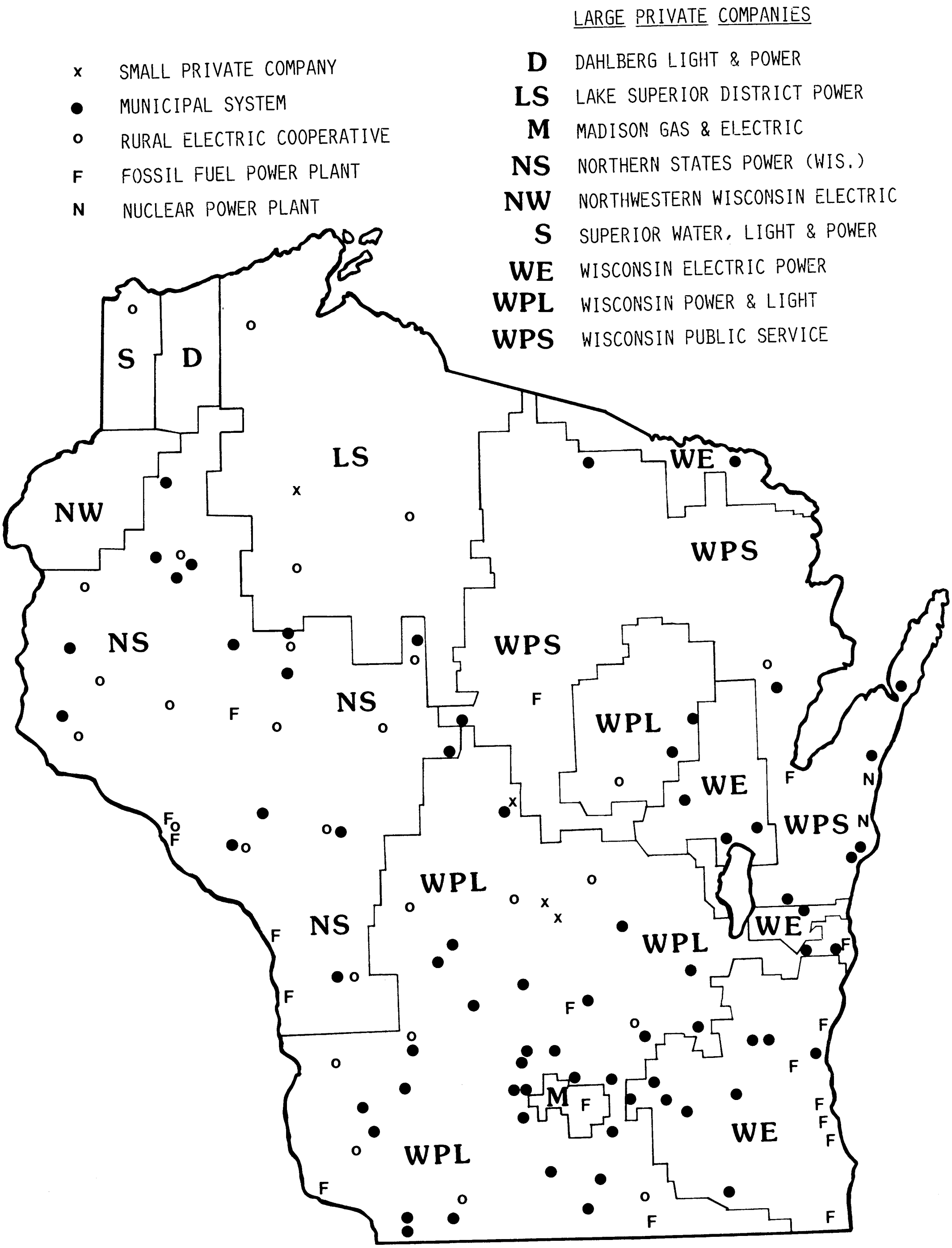

Fig. 1. Wisconsin's electric utility industry.

widely held perception that Wisconsin has a "poor business climate." Whether or not Wisconsin actually has a poor business climate can not be answered here, but it would seem that the quality of the utility industries in the state needs to be part of business climate evaluation. Since this paper's conclusions about the electric utility industry are positive, statements regarding Wisconsin's business climate should be upgraded to reflect this fact. Among other considerations sound electric utilities with relatively low prices should be a strong factor attractive to businesses considering Wisconsin as a place to locate.

Electric Utility Industry in Wisconsin

In Wisconsin, the electric utility industry is composed of 13 privately-owned companies, 83 systems owned by municipalities, and 30 rural electric cooperatives [4]. Except for municipal systems serving towns smaller than 1,000 population, Figure 1 indicates the locations of these utilities. Many of the municipal systems and cooperatives are found in the service areas of Northern States Power (Wisconsin) (NS) and Wisconsin Power and Light (WPL). Wisconsin Electric Power (WE), which is the state's largest utility with over 800,000 customers, dominates the more populous southeastern portion of the state. In contrast, the state's smallest utility, Footville Water and Electric Commission, serves only 340 customers.

Another aspect complicating the utility pattern is a North American Electric Reliability Council (NERC) boundary which divides the state between two NERC regions. NS, Lake Superior District Power (LS), and Superior Water, Light and Power (S) are part of the Mid-Continent Area Power Pool, while the rest of the major utilities in the state belong to the Mid-American Interpool Network. These two NERC regions are two of the nine regions in the United States which are multi-state groups of utilities having a purpose of enhancing the reliability and adequacy of electric power supplies [5]. Effects of this division include the lack of transmission line interconnections between utilities in the two regions and the absence of joint ventures that combine utilities from different NERC regions. Wisconsin's electric utility industry has had many joint ventures to construct power plants, but none, for example, have had NS and WPL working together.

Besides being divided by a NERC boundary, several additional characteristics impact operations of Wisconsin's utilities. First, several of the private utilities serve portions of adjacent states. Northwestern Wisconsin Electric (NW) serves a small part of Minnesota and LS, WE, and Wisconsin Public Service (WPS) each cover parts of Upper Michigan. WPL has a subsidiary company, South Beloit Water, Gas and Electric, operating in Illinois. Second, three of the utilities in Wisconsin are separate subsidiaries of companies based in Minnesota. Northern States (Minnesota) controls NS and LS, while Minnesota Power and Light controls S. These interstate relationships complicate utility operations, especially in terms of regulatory differences. Third, the service areas of WE and WPL are fragmented and most of the major utilities have tortuous inefficient boundaries. A fourth characteristic is the multi-product nature of Wisconsin's electric utilities; besides electricity, many of the utilities provide other products like natural gas, water, and steam heat.

As the above information indicates, Wisconsin's electric utility industry is quite complicated. This complexity occasionally leads to problems and suggests the desirability of simplifying the situation. For example, the cancellation of the NS Tyrone nuclear power plant created jurisdictional problems which led to several court battles [12]. The Tyrone plant, which was planned to provide power for the entire Northern States system (parts of Wisconsin, Minnesota, North Dakota, and South Dakota), was halted by the Wisconsin Public Service Commission

(WPSC) in 1979 after about $75 million had been spent. The problems and litigation developed over Northern States' efforts to recover the $75 million. The public service commissions in the three non-Wisconsin states, feeling that the plant and its abandonment costs were Wisconsin issues, balked at allowing higher electric rates to pay for any abandonment costs. Ultimately the courts ruled that the customers in the non-Wisconsin states would have to pay proportional shares of the $75 million because Tyrone was going to produce electricity for the entire Northern States system. The situation would have been much simpler if only the WPSC and a unaffiliated Wisconsin utility had been involved.

The locations of power plants with a capacity of 100,000 kilowatts or more are also indicated in Figure 1. The process of siting power plants involves the analysis of many factors like rail and water transportation possibilities, proximity to population centers, cooling water supplies, environmental impacts, and the existing transmission network. In Wisconsin, the distribution of power plants demonstrates the importance of closeness to population and cooling water. Almost all the power plants are in or near cities and areas associated with either the Mississippi River, Wisconsin River, or Lake Michigan. Fossil fuels are used by all the major power plants except for the Kewaunee and Point Beach nuclear stations. Among the fossil fuels, the overwhelmingly predominate fuel, representing 65.8 percent of total generation in 1982, is coal [14]. Comparable percentages for oil and natural gas are 0.3 and 0.6 percent, respectively. The remaining generation (33.3 percent) is nuclear with 27.5 percent of the total, and water power, where approximately eighty hydro plants scattered over central and northern Wisconsin contribute 5.8 percent.

Prices

Although electricity prices are determined by state regulatory commissions and are largely based on fuel costs, electricity prices still reflect utility management and operation. Relatively low prices commonly indicate sound planning including proper timing of construction projects and use of strategies to reduce costs. In addition, relatively low prices are sometimes the result of good fortune related to events beyond the utility's control. Conversely, bad planning and ill fortune contribute to relatively high prices.

While electricity prices throughout the nation grew rapidly between 1972 and 1982, Wisconsin's electricity prices increased relatively slowly and currently compare favorably with nearby states (Table 1). While national averages of residential and business prices grew 211 and 258 percent respectively, residential and business prices in Wisconsin increased by 156 and 166 percent respectively. The slower growth in Wisconsin is reflected in changes in national rankings. Especially noteworthy is the improvement in the business price ranking from 43 to 21. This improvement in relative electricity prices between 1972 and 1982 makes Wisconsin business prices much lower than business prices in Illinois, Michigan, and Ohio and competitive with the other nearby states except for Indiana. In the residential sector, Wisconsin has the lowest prices of the eight states. These relatively low electricity prices reduce the costs of living and doing business in Wisconsin, and even though electric bills are usually only a small portion of total expenses for a household or business, the low prices are beneficial to the state.

Table 1 also contains information for several individual companies as well as an average for the larger municipal systems. Considerable price variability exists within the state with the ratio of highest to lowest price ranging between 1.25 to 1.45 for the different sectors and years. In extreme instances, the locations of service area boundaries cause price variability to be much greater and to occur over short distances. For example, Kimberly and Little Chute are

TABLE 1. Interstate and Intrastate Comparisons of Electricity Prices—1972 and 1982 (Dollars)

Area	*1972* *Residential*[1]	*1972* *Business*[2]	*1982* *Residential*	*1982* *Business*
United States	16.55	4269	51.40	15286
Wisconsin	15.84	4408	40.54	11710
Wisconsin's Rank[3]	25	43	12	21
Illinois	17.15	4329	48.33	15748
Indiana	15.19	3818	45.03	9990
Iowa	18.38	4235	45.64	11697
Michigan	14.91	5023	40.93	14762
Minnesota	16.40	4275	43.09	10408
Missouri	16.79	4241	41.99	11137
Ohio	15.90	4083	53.54	14937
LS[4]	16.28	NA	43.91	NA
M	13.32	3301	35.56	13483
NS	14.72	3743	39.22	10034
S	14.95	NA	41.19	NA
WE	16.58	4641	42.41	11419
WPL	13.91	3799	41.19	12699
WPS	17.73	4189	40.56	12662
Municipal[5] Average	13.73	NA	34.55	NA

[1] Monthly residential bill for 750 kilowatt-hours.
[2] Monthly business bill for 200,000 kilowatt-hours and 1,000 kilowatts.
[3] 1 equals state with lowest price.
[4] Refer to Figure 1.
[5] Average of larger municipal systems.
Source: *Typical Electric Bills.* Washington, D.C.: U.S. Energy Information Administration, 1972, 1973, 1982, 1983.

Wisconsin towns of similar size located one mile apart, but Kimberly is served by WE and Little Chute by a municipal system. Thus, in 1982, households in Kimberly paid $15.62 more than households in Little Chute for the same monthly 750 kilowatt-hours of electricity.

Relatively low electricity prices for the state as a whole and for several of the individual utilities are the result of several interrelated factors which have evolved, especially since 1972. The more important of these factors include (1) increased use of less expensive Western coal, (2) no ongoing nuclear power construction projects, (3) slow growth in electricity demand related in part to slow population and economic growth but also in part to strong energy conservation campaigns, (4) widespread application of new rate schedule designs, (5) judicious regulation by the WPSC, and (6) consumer advocacy by the recently formed Citizens Utility Board.

Coal produced by surface mining in Montana, Wyoming, and other Western states usually has a lower delivered price and contains less sulfur than Eastern coal. These advantages have led utilities to use more Western coal. In 1973 (data are not available for 1972), utilities in the eight states in Table 1 obtained 10.3 percent of their coal from the West, but by 1982 this percentage had increased to 26.9 percent [3]. Wisconsin (5.4 percent in 1973 to 50.2 percent in 1982), along with Iowa (26.6 percent to 78.4 percent), exhibited the greatest relative shift to

Western coal among the eight states. In addition to heavy use of Western coal, electricity prices in Wisconsin are held down by the existence of two nuclear stations which were completed before nuclear power costs skyrocketed. The Point Beach station was completed in 1972 at a cost of $172 million and the Kewaunee station was finished in 1974 for $215 million. Costs of around $200 million are much less than the $1 to $6 billion range of costs for finishing, or in some cases, canceling current nuclear projects. While having Point Beach and Kewaunee lowers generating costs, decisions by Wisconsin utilities to not carry through with additional nuclear projects were crucial in keeping current and future prices relatively low. Wisconsin's utilities in the early 1970s, anticipating continued growth in demand, did plan to build more nuclear plants and three projects at Haven, Koshkonong, and Tyrone went beyond the early planning stages. These plants were eventually canceled because state mandated power plant planning along with WPSC urging caused the utilities to realize that demand growth was going to be much less than anticipated and that nuclear projects faced many economic and regulatory uncertainties.

Iowa and Minnesota have a situation like the one in Wisconsin. These two states each have at least one operating nuclear station and no current projects, while all the other nearby states are facing substantial costs related to nuclear projects. For example, the Marble Hill station in Indiana was canceled in early 1984 after $2.5 billion had been spent on the project.

The paucity of power plant construction of all types in Wisconsin helps the utilities keep electricity prices low. Since low levels of power plant construction are the result of projections of continued slow growth in electricity demand (peak demand), this means that slow demand growth contributes to lower prices. Economic problems and limited population increases, aspects largely beyond the utilities' control, are two reasons for slow growth in demand, but in addition, the utilities and the WPSC have made substantial efforts to reduce demand. Foremost among these efforts are time-of-day rates. Time-of-day rates employ higher prices during peak demand periods and lower prices during off-peak periods to encourage customers to shift consumption from peak periods during the day to off-peak periods during the night. In Wisconsin approximately 40 percent of the electricity sold in the state is billed under these rates, whereas a recent national study found that only a tiny percentage of customers chooses to use time-of-day rates [7]. Also, several Wisconsin utilities have extensive load management programs. For example, WE has a program in which residential customers receive a monthly credit of $4.50 on their electric bill in return for letting the utility install a remote control device which allows the utility to turn off the customer's water heater when peak demand conditions arise. This WE program covers approximately 65 percent (93,000) of the customers who possess electric water heaters. Overall, Wisconsin's efforts to shift demand away from peak periods are greater than those of other states and are large enough to lower the need for new power plants.

The WPSC and Citizens Utility Board (CUB) are the final two contributors to Wisconsin's relatively low prices. The WPSC is well regarded nationally and has already been cited for discouraging overly ambitious construction plans and for encouraging wide use of time-of-day rates. More will be said about the WPSC in the section on financial health.

CUB is a consumer group which grew out of the concern that residential customers were poorly represented in regulatory proceedings. The Wisconsin legislature established CUB in 1979 with a mandate to represent consumer interests on utility issues before the WPSC and the legislature [13]. CUB has a growing statewide membership of over 100,000 in 1984 and receives no state

TABLE 2. Interstate and Intrastate Comparisons of Electricity Consumption—1972 and 1982 (Kilowatt-hours)

	1972		1982	
Area	Residential[1]	Business[2]	Residential	Business
United States	641	10145	725	10521
Wisconsin	604	7977	657	9738
Wisconsin's Rank[3]	24	21	17	24
Illinois	529	11820	589	12940
Indiana	655	11594	808	12934
Iowa	606	6029	731	7746
Michigan	543	11992	533	10473
Minnesota	586	8381	696	10139
Missouri	565	7362	736	8214
Ohio	583	16083	664	13544
LS[4]	336	3262	476	5120
M	559	5982	508	6614
NS	654	5289	786	6492
S	387	12840	464	17490
WE	582	10140	601	11480
WPL	611	6417	666	7404
WPS	527	9100	589	10813

[1] Monthly residential consumption per customer.
[2] Monthly business consumption per customer.
[3] 1 equals state with lowest consumption.
[4] Refer to Figure 1.
Source: *Statistical Yearbook of the Electric Utility Industry*. Washington, D.C.: Edison Electric Institute, 1973, 1983.

funding. CUB's contributions to lower electricity prices are its continual and strong opposition to utility requests for rate increases and its efforts to change utility accounting and tax procedures to ones that are more favorable to consumers. CUB claims a number of cases where the WPSC reduced the amount of the rate request because of CUB intervention, but it is difficult to determine the accuracy of these claims. Critics of CUB argue that the group is too antagonistic toward utilities and does not always have the best interests of the consumer in mind because it tends to emphasize short term goals over long term benefits. Also, Wisconsin's CUB is somewhat experimental because it is a relatively young organization and it was the first state citizens utility board to be established in the country (by 1984, Illinois was the second state to form a CUB). In any event, CUB has withstood these problems to become a strong voice supporting lower electricity prices.

CONSUMPTION

Information concerning consumption of electricity is presented in Table 2. The business consumption data encompass commercial, industrial, governmental, and other non-residential uses of electricity. Wisconsin's relative consumption, in contrast to relative electricity prices, exhibits less dramatic change between 1972 and 1982 and more median positions among the nearby states. Looking at residential consumption, Wisconsin grew more slowly than the nation as a whole with its ranking changing to seventeenth. Minnesota, Missouri, and Ohio moved ahead of Wisconsin. Although there are many interrelated factors which influence electricity consumption, Wisconsin's relatively low but still higher residential electricity prices and demand reduction efforts as mentioned in the previous section are two reasons for Wisconsin's slow consumption growth. In addition, relative shifts among the states are influenced by income gains and by greater increase in use of air conditioners in the South and West.

Residential consumption within the state shows all of the utilities except for M increasing from 1972 to 1982 and much variability among the utilities. Colder weather (which reduces the use of air conditioning), somewhat higher electricity prices, and generally lower incomes are reasons for low residential consumption in areas served by LS and S. NS has the highest consumption even though its service area generally has lower incomes and less air conditioning than the service areas of M, WE, WPL, and WPS. The reason for this situation is that NS has proportionally more customers who use electricity instead of natural gas or fuel oil for water heating and home heating.

Examination of interstate variations in business consumption shows a different situation. Wisconsin's business consumption grew relatively rapidly, but its national rank did not change much and its relative position among the nearby states did not change at all. The results for Wisconsin and some of the other states are especially surprising because the economy was strong in 1972 and weak in 1982. Part of the explanation is related to Wisconsin having a weak 1982 economy, but not as weak as several of the major industrial states. Michigan and Ohio, two states with worse economic problems than Wisconsin, continue to have large amounts of business consumption in spite of recession-induced declines in per customer consumption. These states and others bring down the 1982 national value relative to the value for Wisconsin. Another reason for relatively rapid business consumption growth in Wisconsin is electricity price. In the residential sector, Wisconsin's 1982 prices, relatively low but still much higher than 1972, lead to conservation. In the business sector, where price increases can be passed on to the consumer, the same price situation does not slow consumption growth as much.

Discussion of business consumption in states or in utilities is complicated further by the effects of a few customers or a single industry. For example, S in 1982 has the largest number in Table 2 because this utility serves a small number of industrial customers which use very large amounts of electricity. Another city may have as much business activity as Superior, but its consumption per customer may be much less because its businesses are not as electricity-intensive. Also, if a large customer of S should happen to move or be hit by a strike, the figure for S could be much smaller. These aspects help explain why business consumption is much more variable than residential consumption.

A final point with respect to consumption is that it is difficult to judge the desirability of different levels of consumption. Wisconsin has low to medium levels of consumption, but one cannot make a strong argument either way that these levels are appropriate.

Financial Health

Given Wisconsin's combination of relatively low electricity prices and low to medium consumption, one might expect the financial health of the state's utility industry to be low, but it is not. In actuality, Wisconsin utilities are in excellent financial condition. Utility revenues are relatively modest, but operating and capital costs are relatively low, meaning that Wisconsin utilities possess strong cash flows and do not have to keep asking for rate increases to try to catch up with escalating costs. Also, the strong cash position allows the companies to use internal financing for capital projects and to avoid the more expensive credit markets.

Although measurement of electric utility financial health is complicated and sometimes controversial, the items presented in Tables 3 and 4 collectively provide an accurate picture of financial status. The results in Tables 3 and 4 are based on simple averages of values for the privately-owned utilities in a given area. The Moody's ratings of bonds and preferred stocks represent the financial community's opinion concerning the quality of a utility's offerings. Short and long term risk to the investor is the most important determinant in the ratings. In 1972, Wisconsin was among the top group of states, whereas by 1982 many states had suffered ratings declines leaving Wisconsin tied with Texas in the bond ratings and alone at the top in the preferred stock ratings. More recent information from early 1984 indicates that WE, WPL, and WPS are the highest rated electric utilities in the country. It is ironic that Wisconsin's superior ratings are partially the result of not having to borrow heavily for construction projects, while at the same time the superior ratings mean that the utilities could borrow funds more inexpensively.

For the next two measures in Tables 3 and 4, Wisconsin shows mixed results. Both rate of return on common equity (ROE) and interest coverage ratio before taxes (IC) are defined completely in Kanhouwa [9], but basically these statistics compare a utility's net earnings or income to: (1) the total value of the utility's common stock shares for ROE and (2) the utility's total interest expense for IC. Larger values of ROE and IC imply higher relative earnings and stronger financial condition. Even though WE in 1972 and 1982 along with WPL in 1982 have high ROE values, the other utilities bring the average down to a level below the national

TABLE 3. Interstate and Intrastate Comparisons of Electric Utility Financial Health—1972

Area	*Bond Rating*[1]	*Preferred Stock Rating*	*Rate of Return on Common Equity (%)*	*Interest Coverage Ratio Before Taxes*	*Regulatory Climate*
United States	A	NA	12.22	3.08	NA
Wisconsin	AA	NA	10.27	3.32	NA
Wisconsin's Rank[2]	1*	NA	40	16	NA
Illinois	AA	NA	13.18	2.97	NA
Indiana	AA	NA	15.00	3.60	NA
Iowa	AA	NA	12.32	3.74	NA
Michigan	A	NA	11.20	2.78	NA
Minnesota	A	NA	13.08	3.40	NA
Missouri	A	NA	10.61	2.65	NA
Ohio	AA	NA	14.06	3.05	NA
LS[3]	A	NA	11.20	3.91	NA
M	AA	NA	8.40	2.03	NA
NS	AA	NA	9.40	4.41	NA
S	NA	NA	9.50	3.77	NA
WE	AA	NA	11.90	3.94	NA
WPL	AA	NA	10.10	2.58	NA
WPS	A	NA	11.40	2.62	NA

[1] Ratings from high to low: AAA, AA, A, BAA, BA.
[2] For all variables, 1 equals highest rank.
[3] Refer to Figure 1.
* Wisconsin tied for first with 14 other states.
Sources: *Moody's Public Utility Manual.* 1973. *Statistics of Privately Owned Electric Utilities in the United States 1972.* Washington, D.C.: U.S. Federal Power Commission, 1973.

average. This is true for both 1972 and 1982. Wisconsin's ROE is low, but this does not mean that earnings are too low, since the low ROE results from having relatively large amounts of common equity and from the WPSC feeling that utility costs and finances warrant the granting of overall rates of return that are below the national average. Although ROE is low, earnings are more than sufficient to provide an ample margin of safety in covering interest expenses. Careful management of debt has allowed Wisconsin to move from sixteenth nationally to second in 1982 (Colorado was first).

Taken as a whole, the four measures discussed here demonstrate improved financial health for an already solid group of utilities. Wisconsin's electric utility industry was strong financially in 1972, but is even stronger in the 1980s. This is especially noteworthy because during the same period many states and utilities experienced increased financial problems. Among the nearby states, Illinois, Iowa, and Minnesota are above average and far better off than Michigan and Missouri, but do not rank as high as Wisconsin.

Part of the credit for the excellent financial health of Wisconsin's utilities belongs to the WPSC. The final item in Tables 3 and 4,

TABLE 4. Interstate and Intrastate Comparisons of Electric Utility Financial Health—1982

Area	*Bond Rating*[1]	*Preferred Stock Rating*[1]	*Rate of Return on Common Equity (%)*	*Interest Coverage Ratio Before Taxes*	*Regulatory*[2] *Climate*
United States	A2	A3	14.03	2.60	C
Wisconsin	AA2	AA1	13.44	3.73	B
Wisconsin's Rank[3]	1*	1	26	2	5**
Illinois	AA3	AA2	14.48	2.83	C+
Indiana	A2	A3	13.00	2.46	A
Iowa	AA3	A2	18.30	2.82	C−
Michigan	BAA3	BA1	9.66	1.85	C−
Minnesota	A1	AA3	14.18	2.86	C
Missouri	BAA1	BAA2	13.33	2.54	E
Ohio	A3	BAA1	13.16	2.15	B−
LS[4]	A3	NA	12.90	5.27	NA
M	AA2	NA	11.30	3.69	NA
NS	AA2	NA	9.80	2.93	NA
S	NA	NA	14.80	2.55	NA
WE	AA1	AA1	15.90	4.22	NA
WPL	AA1	AA1	15.80	3.88	NA
WPS	AA1	AA1	13.60	3.55	NA

[1] Ratings from high to low: AAA1, AAA2, AAA3, AA1, AA2, AA3, A1, A2, A3, BAA1, BAA2, BAA3, BA1, BA2, BA3.

[2] Climate rating: A (highest) to E (lowest).

[3] For all variables, 1 equals highest rank.

[4] Refer to Figure 1.

* Wisconsin tied for first with one other state.

** Wisconsin tied for fifth with one other state.

Sources: Luftig, Mark D. and Scott Sartorius. *Salomon Brothers Electric Utility Regulation—Semiannual Review.* February 1983, August 1983.

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labeled regulatory climate, is an assessment of how favorable the public service commission rulings are to the utilities and their stockholders. The WPSC, considered to be fairly favorable to the electric utilities, has at the same time closely monitored capital expenses (power plants), encouraged good utility management, and used sophisticated approaches to resolving utility issues [8]. The results of this regulatory environment provide Wisconsin with solid utilities that are able to sell electricity at below average prices. Among the other nearby states, there is surprisingly little correspondence between regulatory climate and electricity price levels. Missouri's public service commission does not grant large rate increases and is very unfavorable to utilities, but Missouri's electricity prices are similar to those in Wisconsin and Missouri's utilities have much poorer financial health. One explanation for this situation is that more favorable regulation allows the utilities borrow at lower interest rates and to be more flexible in controlling costs.

Another issue related to financial health is utility diversification. Utilities throughout the country, wanting to grow and expand in spite of slow growth in electricity demand, are increasingly interested in becoming involved in other businesses besides selling electricity. Some minor diversifying has occurred in Wisconsin, but the principal issue in the state revolves around legislation to allow the state's utilities to organize utility holding companies [1]. Utility holding companies, which would permit utility and non-utility activities to be kept separate, are desired by the utilities so that WPSC regulation would not cover the non-utility activities. The utilities argue that non-utility enterprises need to be free from regulation in order to be competitive. The utilities also emphasize strongly the possibility of creating new jobs when the non-utility businesses are established. Opponents of utility holding companies (like CUB) object to the increased potential for deterioration in the cost and quality of utility service and to the possibility of unfair competition adversely affecting small business. There have been instances in other parts of the nation, where utility holding companies have shed lackluster utility subsidiaries leaving the utility subsidiaries with financial problems. Also, occasionally the better managers migrate to the "more glamorous" non-utility businesses, and thereby, worsen utility management. These drawbacks reduce the attractiveness of utility holding companies so that it is difficult to decide whether they should be allowed in Wisconsin.

The Wisconsin legislature has not reached a final decision about utility holding companies. In 1983, the bill authorizing holding companies was tabled in the Senate by a close vote. During 1984, the bill has not been reintroduced primarily because the bill's complex language is being rewritten to try to satisfy some of the bill's opponents. Utility diversification in Wisconsin, at least in terms of holding companies, is presently at a standstill.

Conclusion

This paper examines the status of Wisconsin's electric utility industry by focusing on the state's major privately-owned electric utilities. The examination finds the utility industry to be spatially and jurisdictionally complex. Per customer consumption of electricity in the state is relatively modest. In addition, the industry along with the WPSC is able to combine relatively low electricity prices and financial strength. Wisconsin's situation is significant in terms of emphasizing time-of-day rates, developing the first citizens utility board, and showing the impact of having no expensive new nuclear projects under construction. Wisconsin's electric utilities represent a high quality portion of the state's infrastructure which should help to attract new businesses to the state. Efforts to promote economic growth in Wisconsin need to stress the character of its electric utility industry.

The future of Wisconsin's electric utility industry shows two possible causes of concern, but on the whole the future seems bright. One concern is the potential for utility diversification to be allowed without sufficient safeguards for utility customers. A second concern relates to acid rain [10]. Acid rain, caused in part by sulfur oxides emitted from coal power plants, is a major environmental issue. There is a strong likelihood that stricter air pollution regulations will be enacted, which would substantially increase pollution control costs for utilities and their customers. Wisconsin's utilities, using much coal, would be adversely affected by acid rain regulations, but at least much of the coal being used is low sulfur Western coal.

On the positive side for the future, Wisconsin's utilities expect to be able to avoid construction of new power plants until the middle 1990s and to maintain relatively low electricity prices. Evidence of the last point occurred in early 1984 when the WPSC lowered rates for WE. Another possible development which could lower costs is the importation of electricity from Canada [6]. Manitoba, in particular, has hydro power potential which could be developed for Midwestern markets including Wisconsin. These positive factors combined with continued careful management and regulation should outweigh any future concerns, thereby maintaining the state's strong electric utility industry.

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THE SOUTHERN SOCIAL ART OF ROBERT GWATHMEY

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"All serious creative work must be at bottom autobiographical," wrote the Southern-born novelist Thomas Wolfe in 1936.* "A man must use the material and experience of his own life if he is to create anything that has substantial value." Wolfe wrote these words in the middle of what has become known as the Southern Renaissance, a cultural movement that produced William Faulkner, Robert Penn Warren, Eudora Welty, Erskine Caldwell, and many other skilled and influential authors. Not only the quality of their writing but also the subject matter dealt with by Southern writers of this era has intrigued literary critics throughout the world. Southern writers struggled with the heritage of slavery, intense racial interaction, brutal poverty, and the Lost Cause of the Confederacy. The "sense of place" and the mixing of individual identity with social and geographic surroundings, have fascinated both Southerners and non-Southerners, with the former group developing an intense self-consciousness over the years. Thomas Wolfe's comments about the importance of autobiographical expression in literary work could have come just as readily from the pen or typewriter of many other Southern writers of this era.[1]

Recent work by literary and cultural historians has shed considerable light on writers during the Southern cultural awakening, but surprisingly little attention has been given to artists of the same period. The discussion of Southern art in *The Encyclopedia of Southern History* virtually ignores Southern painting in the middle third of the twentieth century. Even George B. Tindall's massive survey, *The Emergence of the New South, 1913-1945,* fails to discuss the visual arts even though he devotes two full chapters to literature. The cultural historian Henry Nash Smith recently questioned whether the term "Southern Renaissance" could accurately be used because "the record shows no outstanding Southern achievement in the graphic arts . . . during this period . . ." His conclusion reflects the current consensus on Southern art in the mid-twentieth century.[2]

"An artist is motivated by the fact that he sees something worthy of recording," Robert Gwathmey once observed. "However, in the final analysis, if it is not to a great extent autobiographical . . . it will lack conviction." The similarity between Gwathmey's observations and those of Thomas Wolfe is more than coincidental, for the two shared sentiments about the creative process. They differed because Gwathmey expressed his ideas most often with paint on canvas rather than with typewriter or pen. In doing so, Gwathmey exemplified the visual expression of Southern culture in the middle years of the twentieth century.[3]

As Gwathmey himself suggested, the keys to his art are his personal experiences as a white Southerner who encountered the stark contrasts of race and caste that characterized society in his region. The influence that this social context had on his art developed slowly and did not manifest itself until well into Gwathmey's adult years. He was born in Richmond, Virginia, in 1903, into a respected white family that traced its roots eight generations back into Virginia history.

*Previous versions of this paper were presented at the 11th Biennial History Conference on New Approaches to Social and Cultural History at Kutztown, Pa., on March 26, 1979, at the 85th Annual Meeting of the Michigan Academy of Science, Arts, and Letters at Ann Arbor, Mi., on March 20, 1981, and at the 5th Annual Meeting of the American Culture Association in Wichita, Ks., on April 26, 1983.

Although his home environment was comfortable during his early years, it was not affluent. His father, a railroad engineer, died in a train accident before Gwathmey was born and left only a small death benefit from the railroad. He was raised in an environment dominated by a mother and sisters who contributed to the maintenance of the family welfare and ultimately to Gwathmey's pursuit of a career as an artist. Despite their lack of wealth, the family maintained a veneer of gentility in what Gwathmey called a "middle class neighborhood." He found time to enjoy sports, reading, and fishing with friends and relatives.[4]

In this period of the early twentieth century, racial segregation was hardening in the South, and Gwathmey developed an awareness of class and racial distinctions that he later depicted in his art. "As a youth I was conscious of harsh inequalities in my community," he recalled of his high school years in Richmond, during which he worked in a lumberyard, a florist shop and a department store. The structure of Southern society intrigued but also disturbed him. He remembered hearing Norman Thomas speak when the Socialist leader stopped in Richmond during summer speaking tours. But Gwathmey's interest in social protest proved little more than curiosity during these years.[5]

The 1920s were a critical period for Gwathmey as he developed an interest in art and in the wider world outside the South. After graduating from high school he spent two years as a railway clerk. In 1924 he decided to enroll in a business course at North Carolina State in Raleigh, but after only a year he left and obtained a summer job on an American freighter that took him far from home for the first time. When his ship stopped at major European ports, Gwathmey occasionally took time to visit art galleries and museums. On board ship, he used his free hours to sketch fellow crew members at work. Clearly, this was an influential time in the development as an artist, for when the twenty-two year old returned to the United States he abandoned plans for a career in business and enrolled in the art program at the Maryland Institute in Baltimore.[6]

Whereas his visit to Europe had opened his eyes to a world of culture not widely available in the South, his experience in Baltimore provided him a different vantage point on society in his native region. He later described his arrival in the Maryland city: "When I went to Baltimore to study art, the first thing I saw was Negro policemen and statues of Yankee generals. It was my first trip North, the farthest North I'd ever been, and I was 22 years old." Returning to Richmond from Baltimore allowed him to look anew at his region. "When I got back home," he observed, "I was shocked by the poverty. The most shocking thing was the Negroes, the oppressed segment. If I had never gone back home, perhaps I would never have painted the Negro."[7]

Appropriately for an artist, he remembered his new perspective on Southern society in very visual terms: "I was shocked at the red clay. The green pine trees and red clay were everywhere. The Negro seemed to be everywhere, too. . . . But he was a thing apart, so segregated." While this new awareness of the racial and caste system of the South did not influence Gwathmey's art for at least another decade, it started him thinking about ways of portraying blacks that would avoid quaintness of the kind sometimes found in the works of the nineteenth-century painters Eastman Johnson and Winslow Homer. "The Negro never seems picturesque to me," he later observed.[8]

In 1926, after a year in Baltimore, Gwathmey went to Philadelphia to study at the Pennsylvania Academy of the Fine Arts, one of the most prestigious art schools in the nation. Part-time jobs he held while studying there, including one teaching art at a settlement house in an immigrant neighborhood, gave him a chance to work closely with people from cultural backgrounds different from his own. Summer fellowships in 1929 and 1930 allowed him to travel and to study art in Europe, where he also deepened his appreciation of issues of social class, especially as the effects of the Great Depression were being felt.[9]

Gwathmey's artistic stance at this time reflected the formal training he had received under Franklin Watkins, Daniel Garber, and George Harding at the Pennsylvania Academy. He had not yet settled on the subject matter nor on the distinctive style that he developed in his mature paintings. He remembered the Thirties as a time of economic problems and as a period when he worked to define his own art. "It takes about ten years to wash yourself of academic dogma," he later explained. In 1938 he made an artistic break with his past and destroyed virtually all of his previous work, leaving only those pieces consistent with the themes and techniques he was adopting as his own. One of his earliest surviving works, *The Hitchhiker,* reflects both his new interest in timely social subject matter of the Depression era but also some of the latent artistic influences of Watkins.[10]

From the late Thirties onward Gwathmey's art drew heavily on his life experience, focusing to a great degree on Southern subjects, particularly those revealing the lives of common people and their relationships to others in society. His frequent portrayal of blacks as a group and as individuals has sometimes caused him to be categorized incorrectly as a single-minded painter of racial scenes. In reality, Gwathmey's paintings were explorations of the nature of Southern life and community which often expressed his belief in the dignity of people so often taken for granted. His artistic expressions of the simple beauty of everyday life and labor of blacks and whites were sometimes made more effective by the use of juxtaposition and satire of the dominant class of the region.[11]

During the Thirties Gwathmey taught art at Beaver College near Philadelphia. While teaching did not pay very well and ended in a messy dispute with the college's administration, the position gave him more security and income than many artists had during the Depression and it required him to be in the classroom only two days each week. This schedule allowed him time to travel to New York City, where he absorbed the ideas of and became increasingly active in left wing artistic and political worlds. Although Gwathmey did not depend on government arts projects for his livelihood, he became friends with many artists who were desperate and depended on federal art programs in order to survive. He often traveled to Washington and New York on behalf of government support for cultural projects and became an active member of the Artists' Union movement in Philadelphia. These activities heightened his commitment to social change, particularly in race relations. In the Philadelphia Artists' Union "for the first time I met Negroes on an equal plane," he remembered.[12]

Despite the attraction of northern cities such as Philadelphia, Pittsburgh and New York, where Gwathmey eventually held teaching positions, he continued to be pulled back to and influenced by the South. During the Thirties, he made periodic trips back home to Virginia that caused him to maintain an interest in Southern social conditions that otherwise he might have lost. In 1935 he married Rosalie Hook, an art student from Charlotte, North Carolina, where he retreated after being fired from Beaver College. A Rosenwald Foundation fellowship in 1944 allowed him to spend a year living and working on a North Carolina tobacco farm, where he worked with three different sharecroppers three days a week. Although his schedule was clearly not as backbreaking as that of the men and women with whom he worked, his experience served as a symbolic link between his life as an artist and the world of the South from which he had emerged.[13]

Even though he lived in the North for

most of the rest of his life, he regularly visited the South until his later years to make working drawings or to put final details on canvases. Each trip renewed his interest in Southern social conditions as a focus for his art. In fact, a year spent in Paris during the late Forties proved artistically unproductive because he found it impossible to be motivated as he was when he experienced the Southern environment. "You go home," he later recalled. "You see things you had almost forgotten. It's always shocking." Most disturbing were what he called "the acute blind spots" of his "boyhood friends and associates."[14]

While Gwathmey's style evolved over the years, a remarkable consistency ran through his art for over forty years. Angular, elongated human figures are often found in his paintings; flat planes of color give many of his works from the Fifties onward a feeling of cubism. The major significance of Gwathmey's painting lies in his use of this style to treat social subjects, including the racial and caste system of the South. "When people ask me why I paint the Negro," he observed in 1946, "I ask 'Don't artists have eyes?'" His answer reveals not just a preference for art as social criticism but also a belief that an artist ought to devote himself to recording everyday reality as he sees it. Although his wife was an accomplished photographer, Gwathmey himself believed painting could more effectively convey reality and used photographs only to stimulate ideas he would later develop on canvas. For him, rural blacks were a part of Southern life as he had known it during his formative years. Paul Robeson speculated that "Gwathmey's identification with the South, brought him close to the culture of Africa and its classic sculpture. . . . He succeeded in adopting the elements of African sculpture and adding his own broader conception of social art." Indeed, many of Gwathmey's figures resemble African sculpture, with its accentuated height and angularity. *The Observer* (fig. 1), done in 1960 and one of his most famous works, could just as well be a scene from Africa as from the American South. The influence of black art is apparent. Gwathmey's strength as a painter comes not from photographic realism but from his being a critical observer of life in the rural South and a skillful portrayer of the emotional impact of the images he saw in society around him.[15]

His paintings include two major subject categories. In one group he used satire and caricature as a technique of social criticism. The painting called *Poll Tax Country* (fig. 2) depicts a white Southern orator haranguing from a bandstand. Below him, blacks ignore his speech and go about their work of hoeing. On the platform, lending unspoken support to the racist talk, are five figures: one black—an educator in academic garb—and four whites—a society woman, a clergyman, a hooded clansman, and a man who may be a sheriff or a representative of the poor class of whites who are asked to stand by the upper class racists. On the roof of the speaker's platform is a black crow, a frequent symbol in Gwathmey's art that may depict the pervasiveness and inevitable decay of the segregation system that Southerners called Jim Crow.

Another painting where Gwathmey uses satire and caricature focuses on a single white man. Titled *The Standard Bearer* (fig. 3), this work strikes even more clearly at what Gwathmey saw as the hypocrisy of the Southern political system. The rotund politician holds aloft symbols of justice and equality while at his feet lies a lynching rope, the instrument of the suppression of blacks. At the top of the standard rests the black crow of segregation. Other paintings contain striking uses of satire and caricature. In *Hoeing,* done in 1943, Gwathmey contrasts languid whites on one side of the painting with a young and powerful black laborer who dominates the center of the work.

The second category of Gwathmey's works may be called social documentaries. They occasionally contain an element of

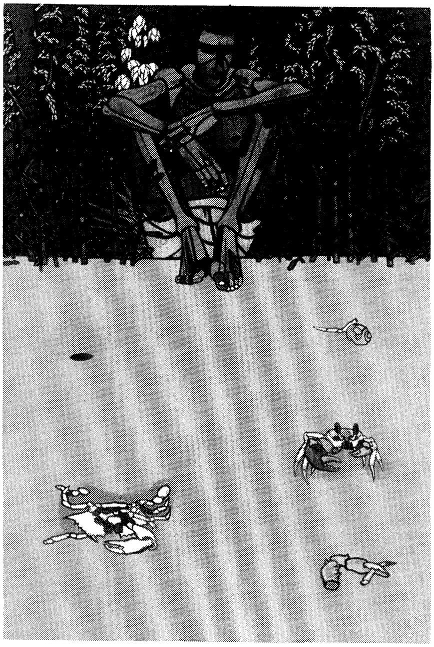

Figure 1 *The Observer,* oil on canvas, 1960, 48-1/8″ × 34″ National Museum of American Art, Smithsonian Institution, Gift of S. C. Johnson and Son, Inc.

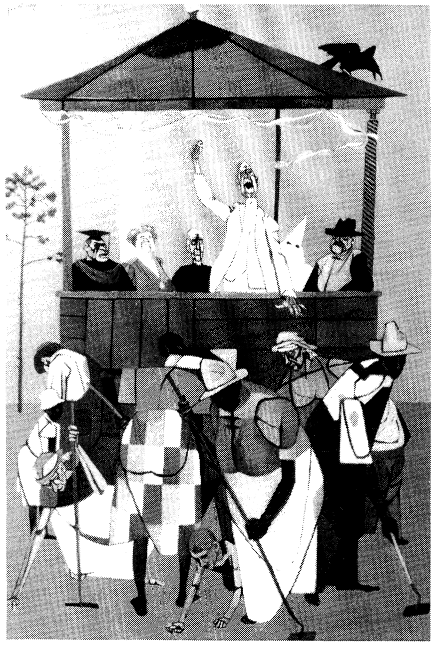

Figure 2 *Poll Tax Country,* oil on canvas, n.d., 41″ × 28″ Hirshhorn Museum and Sculpture Garden, Smithsonian Institution.

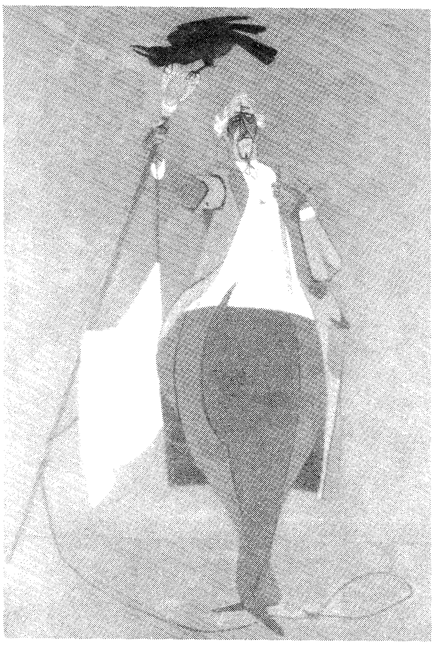

Figure 3 *Standard Bearer,* oil on canvas, 1946, 33¾″ × 24″ Museu de Arte Contemporânea da Universidade de São Paulo. Photograph by Gerson Zanini.

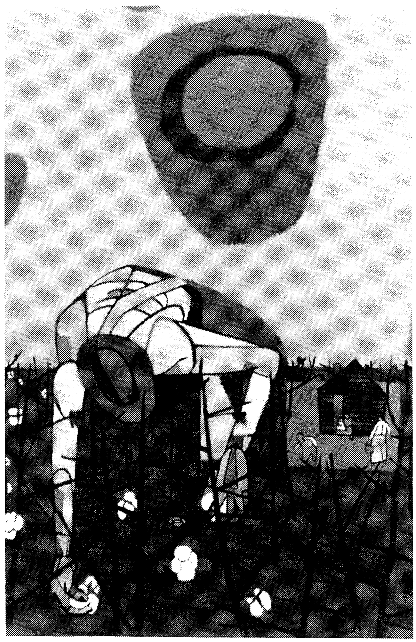

Figure 4 *Sun-Up,* oil on canvas, c. 1955, 16″ × 11″ Philadelphia Museum of Art, Louis E. Stern Collection.

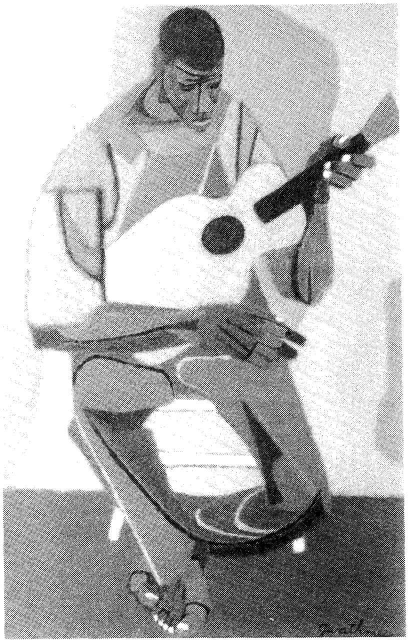

Figure 5 *Playing,* oil on canvas, n.d., 15″ × 10″ Hirshhorn Museum and Sculpture Garden, Smithsonian Institution.

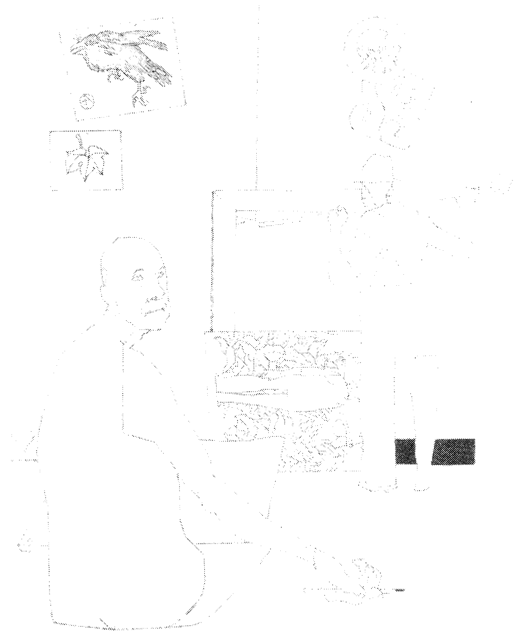

Figure 7 *Self Portrait,* lithograph, n.d., 26½″ × 23½″, Flint Institute of Arts, Gift of Jack B. Pierson in memory of Robert Martin Purcell.

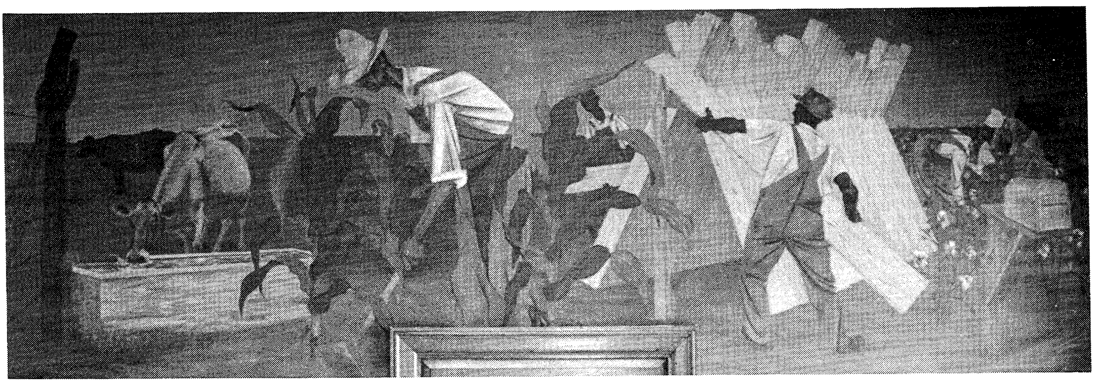

Figure 6 *The Countryside,* post office mural at Eutaw, Alabama, 1941, 13′4″ × 4′8″, General Services Administration, Public Building Service.

social protest with graphic depiction of the starkness of the lives of Southern blacks. But more often his documentaries focus on the gentle theme of the dignity of Southern laborers and their families as they go about their daily tasks. Among his favorite subjects were men and women at work as individuals or in groups as in *Sun-Up* (fig. 4). The details of his paintings of tobacco and cotton field workers demonstrate a familiarity with the subject matter so that overalls, hoes, buckets, and even weeds in the fields are authentic. He described one painting as "part of a scene I know intimately."[16] His beautiful painting of *Queen Anne's Lace,* which contains no human figures, revealed his concern with carefully documenting the details of nature.

Gwathmey portrayed more than just the work experience. Among his best paintings are those that reveal other facets of Southern life. *Family Portrait* offers a strong statement about the strength of the black family. Music has frequently appeared as a subject of Gwathmey's paintings, as in *Playing* (fig. 5). Some of his most powerful images result from the juxtaposition of a single black figure with an arrangement of flowers. *Portrait of a Farmer's Wife* and *Field Flowers* speak elegantly of the value of natural beauty in the life of the common laborer.

During the late 1930s Gwathmey began to advance in the American art world. In 1938 he became an instructor at the Carnegie Institute of Technology in Pittsburgh and won a competition to hold a one-man exhibition at the American Contemporary Art Gallery in New York City. In 1939 he received a commission from the federal Section of Fine Arts to paint a mural in the post office at Eutaw, Alabama, in the heart of the black belt. Rejecting suggestions of the local postmaster that he depict scenes of the Confederacy and the greatness of Eutaw, Gwathmey toured surrounding Greene County and did a mural called *The Countryside* (fig. 6), which reflect the social reality of the region. It contained three white men, two black men, and focused on the rural laborers of the area.[17]

Gwathmey received his greatest acclaim during the Forties. Galleries and individuals acquired his works as soon as he painted them, and he exhibited at shows that highlighted the best of contemporary American painting, including one organized during World War II by Artists for Victory. In 1942 he moved to a position at the Cooper Union in New York City, where he remained on the faculty until 1968. He called it "the best place in the world to teach—just as New York is the best place in the world for a painter to live." By 1950, when Gwathmey was invited to teach for a summer at the experimental Black Mountain College in North Carolina, he was clearly one of the most influential American artists. Although he continued to exhibit and to win prizes, the increasing domination of Abstract Expressionism during the Fifties pushed Gwathmey's painting out of the mainstream of American art.[18]

Gwathmey's art continued to develop into the 1980s, when a return of critical interest in realism brought him new attention. Although he still exhibited the dual tendencies of social criticism and social documentation, he also occasionally recorded images of the mainstream of American life. Gwathmey did a sequence of paintings on the 1957 World Series in Milwaukee for *Sports Illustrated,* which said the artist "was impressed . . . that much of the crowd [at the games] was comprised of family units, often including grandparents and grandchildren." The sports magazine also described him as having "a positive attitude toward life." Nonetheless, he reflected bitterly in the 1974 social surrealistic painting *Late Twentieth Century* on real and potential violence in contemporary life.[19]

Even though Gwathmey's paintings still recalled his Southern origins, his life became more remote from them. He eventually became a moderately wealthy member of the New York artistic community. "It's fearful to think that today's times are so affluent for me," he told interviewer Studs Terkel in the late Sixties. "I live real well, real well." Today he resides and works at a home and studio in Amagansett, Long Island, designed by his son, the post-modernist architect Charles Gwathmey. Since retiring in 1968 from his position at Cooper Union, where he was an extremely influential and popular instructor, he has been a visiting professor at several universities and received many awards in art and design. He remains active in New York artists' and writers' groups and continues to devote himself to social and political protest; although he recently has been slowed by Parkinson's disease. Throughout his life, Gwathmey was attracted to the social function of art and the artist. His own activities during the Cold War and Vietnam eras demonstrated a willingness to defend unpopular causes. In the middle of the Abstract Expressionist vogue of the Fifties, he deplored what he believed was the meaninglessness of much abstract art. He preferred to portray living things in his art.[20]

Until very recently when Southerners talked about art in their region they most often meant literary art. This dominance of literature has convinced some of today's Southern visual artists that they have no forebears. "We are the first generation of Southern artists," one of them proudly declared. The Southern cultural Renaissance of the mid-twentieth century focused intensely on the decadence and hypocrisy that pervaded Southern society, but it also emphasized the power of the history that Southerners shared. Robert Gwathmey revealed that Southern social history could create remarkable visual as well as literary images. His use of paint and canvas to depict the Southern racial and social system now deserves some of the attention that has been given to Southern writers.[21]

Only once did Gwathmey do a self-portrait (fig. 7). It was a lithograph done for the opening of the gallery of his friend and dealer Terry Dintenfass. Gwathmey, the artist, is seated on the floor with brush or pen in hand. A partially complete canvas rests on its side in front of him. In the room with him is a Southern fieldworker similar to those who appeared frequently in his works. On the studio wall, along with other mysterious and intriguing symbols, he placed the figure of a crow of the kind that rested above the heads of white Southerners in some of his paintings. It is deformed but still recognizable, perhaps an acknowledgement that he, too, carried the heritage of his race and region.

Notes

[1] Thomas Wolfe, *The Story of a Novel* (New York, 1936), p. 21.

[2] David C. Roller and Robert W. Twyman, eds., *The Encyclopedia of Southern History* (Baton Rouge, La., 1979), pp. 80-81; George B. Tindall, *The Emergence of the New South, 1913-1945* (Baton Rouge, La., 1967), pp. 285-317; among the recent studies are Morton Sosna, *In Search of the Silent South: Southern Liberals and the Race Issue* (New York, 1977); Michael O'Brien, *The Idea of the American South, 1920-1941* (Baltimore, 1979); Richard H. King, *A Southern Renaissance; The Cultural Awakening of the American South, 1930-1955* (New York, 1980); Daniel Joseph Singal, *The War Within: From Victorian to Modernist Thought in the South, 1919-1945* (Chapel Hill, N.C., 1982); Fred Hobson, *Tell About the South; The Southern Rage to Explain* (Baton Rouge, La., 1983); Henry Nash Smith, "Fathers and Sons Southern-Style," *New York Times Book Review* (June 1, 1980), p. 12; also C. Vann Woodward, "Why the Southern Renaissance?" *Virginia Quarterly Review,* 51 (1975), 222-239.

[3] Gwathmey quoted in Roland F. Pease, Jr., "Gwathmey," in *Art USA Now,* ed. Lee Nordness, vol. 1 (New York, 1963), unpag. insert between pp. 122-123.

[4] Elizabeth McCausland, "Robert Gwathmey," *Magazine of Art* (April 1946), p. 149; Harry Salpeter, "Gwathmey's Editorial Art," *Esquire* (June 1944), p. 83.

[5] McCausland, "Robert Gwathmey," pp. 149-150; Pease, "Gwathmey," unpag.; Paul Robeson, Introduction to *Robert Gwathmey,* ACA Gallery exhibition catalog (New York, 1946), unpag.

[6] *Current biography: Who's News and Why, 1943,* ed. Maxine Block (New York, 1944), p. 261; Salpeter, "Gwathmey's Editorial Art," p. 83.

[7] Gwathmey quoted in McCausland, "Robert Gwathmey," p. 149.

[8] Gwathmey quoted in *Ibid.*, p. 149-150.

[9] *Ibid; Current Biography, 1943*, p. 261.

[10] Gwathmey quoted in *Current Biography, 1943,* p. 262; Salpeter, "Gwathmey's Editorial Art," p. 131.

[11] Daniel Grant, "Compassion Colored By a Lifetime," *Newsday Part II* (July 22, 1984), p. 4.

[12] Studs Terkel, *Hard Times: An Oral History of the Great Depression* (New York, 1970), p. 373; Gwathmey quoted in McCausland, "Robert Gwathmey," p. 149.

[13] Grant, "Compassion Colored By a Lifetime," p. 5; McCausland, "Robert Gwathmey," p. 150; Terkel, *Hard Times,* p. 374; Pease, "Gwathmey," unpag.

[14] Barbara Delatiner, "'He Paints What Is in His Heart,'" *New York Times* (July 22, 1984), Long Island Section, p. 13; Gwathmey quoted in McCausland, "Robert Gwathmey," p. 150.

[15] Delatiner, "'He Paints What Is in His Heart,'" p. 13; Robeson, Introduction to *Robert Gwathmey,* unpag.; McCausland, "Robert Gwathmey," p. 147.

[16] Gwathmey quoted in College of Fine and Applied Arts, *University of Illinois Exhibition of Contemporary American Painting* (Urbana, Ill., 1951), p. 184. The painting was *The Cotton Picker.*

[17] *Current Biography, 1943,* p. 262.

[18] Quoted in *Ibid.;* Gwathmey turned down the invitation to Black Mountain because of prior commitments. Martin Duberman, *Black Mountain: An Experiment in Community* (Garden City, N.Y., 1973), p. 347.

[19] "Fervor in Milwaukee," *Sports Illustrated* (April 14, 1958), pp. 102-106.

[20] Terkel, *Hard Times,* p. 375; John Hejduk, "Armadillos," *John Hejduk: 7 Houses,* ed. Kenneth Frampton (New York, 1980), p. 4; Grant, "Compassion Colored By a Lifetime," p. 5; Elaine Benson, "Robert Gwathmey, Artist, Gentleman, Political Activist, A Hamptons Favorite, *The Hamptons* (August 1984), p. 13; Robert Gwathmey, "Art for Art's Sake?" Paper delivered at the International Design Conference in Aspen on Design and Human Problems, 1958.

[21] For example, Donald Davidson, "A Mirror for Artists, "*I'll Take My Stand: The South and the Agrarian Tradition* (New York, 1930), pp. 28-60; Bill Dunlap quoted in Mary Lynn Kotz, "The Southern Muse," *ArtNews* (February 1983), p. 78.

PIONEERING WITH PLANS AND PLANTS: H.W.S. CLEVELAND BRINGS LANDSCAPE ARCHITECTURE TO WISCONSIN

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Horace William Shaler Cleveland was the first professional landscape architect to practice in Wisconsin. His work in this state preceded that of such better-known colleagues as Frederick Law Olmsted, who designed important parks in Milwaukee; Jens Jensen, who shaped landscapes throughout the Midwest and founded "The Clearing" in Door County; and John Nolan, who developed the proposal for Wisconsin's state park system and planned important public open space projects in Madison, Milwaukee, Janesville, Green Bay and LaCrosse.[1] Yet, relatively little is known of this visionary environmentalist, and he has not received the scholarly attention his accomplishments justify.

During his professional career spanning more than fifty years, Cleveland pioneered significant contributions to the planning, design and management of the land. Not only did he provide an important link between the American West and the fledgling field of landscape architecture beginning in the East; he also was perhaps the most persistent and articulate nineteenth century spokesman regarding the comprehensive scope of his new profession. This activity, as he perceived it, extended far beyond the ". . . adornment of professedly ornamental grounds . . . and the private estates of men of wealth,"[2] to encompass, as he so eloquently wrote, ". . . the art of arranging land so as to adapt it most conveniently, economically and gracefully, to any of the varied wants of civilization."[3]

The descendent of an early New England seafaring family, Horace William Shaler Cleveland was born in Lancaster, Massachusetts in 1814. His grandfather and father had prospered from an active maritime business and, as a young man, Cleveland received not only a formal education, but benefited from his father's broad literary interests and sailing experiences.

At the age of fourteen, Cleveland's family moved to Cuba, where his father became Vice-Counsel. Here, young Horace worked on a coffee plantation, where he learned native mulching techniques that he would later utilize on his own farm and in many aspects of his landscape architectural practice, particularly those concerned with forest management.

Two years later, Cleveland returned to Massachusetts where he took up the study of civil engineering. This training led to employment as a land surveyor in central Illinois and Maine. The Illinois work, starting in 1833, provided his first opportunity to visit the Midwest—at that time a wild, virtually undeveloped frontier.[4] This adventure undoubtedly left a lasting impression upon the twenty-one year old and the area's potential influenced his later decision to move west. After returning to New York on horseback, Cleveland turned to a career in agriculture and horticulture, buying a farm near Burlington, New Jersey, in 1841. During this period he also founded the New Jersey Horticultural Society and served as the organization's Corresponding Secretary.[5]

The combination of experience in civil engineering, agriculture and horticulture served as a springboard for Cleveland's long and productive career in landscape architecture, or landscape gardening as it was known in the 1840's. Returning to New England in 1854, he established an active landscape architectural practice with Robert Morris

Copeland. The two men set up an office in Boston and engaged in work to "... furnish plans for the laying out and improvement of Cemeteries, Public Squares, Pleasure Grounds, Farms and Gardens."[6] Seeking the prestigious commission to plan Central Park in New York, they submitted a design for the 1857 competition, but it was not chosen as the winning entry.

Little is known of Cleveland's work during the ensuing decade. However, in 1868, he went to work with Frederick Law Olmsted, the founder of landscape architecture in America, where he worked on plans for Prospect Park in Brooklyn.[7] During this time, the Olmsted office was actively engaged in preparing a new, innovative subdivision layout for Riverside, Illinois, only nine miles from Chicago. This project may have revived Cleveland's interest in the West, developed more than thirty years earlier. In 1869 he established his landscape architectural practice in Chicago. He could now become more intimately involved with new and exciting professional opportunities in this young and dynamic city and also with the rapid development occurring throughout the Midwest.

It was from Chicago that Cleveland, with missionary zeal, worked to extend the frontier of landscape architectural practice into America's heartland. A prolific writer and engaging speaker, he appealed for orderly development of the land and set forth his philosophies of land planning and design in a variety of pamphlets, articles, letters, and his remarkably perceptive book *Landscape Architecture as Applied to the Wants of the West*.[8]

In this publication, he eloquently stressed the landscape architect's social role and responsibility in the newly-developing region, where a surge in homesteading activity and the efforts of railroad companies and land speculators stamped, with mechanical regularity, the gridiron plan upon the land.

By 1871, he had formed a loose partnership with William M. R. French, a creative civil engineer who later became Director of the Chicago Art Institute. Cleveland's work now began to assume important new dimensions and encompassed the design of cemeteries, suburban residential developments, vacation resorts, parks, university grounds and other institutional projects, and the sites for several new state capitol buildings. Their active practice eventually extended throughout the region to include projects in Illinois and Wisconsin, as well as work in Iowa, Indiana, Kansas, Minnesota and Nebraska.

ADVERTISEMENT.

CLEVELAND & FRENCH,

Landscape Architects and Engineers,

38 PORTLAND BLOCK,

S. E. cor. Dearborn & Washington Sts.,

CHICAGO, ILL.

Fig. 1. Title from a pamphlet advertising the professional services of Cleveland and his civil engineer partner William M. R. French, after they had established an office in Chicago in 1871. (Photo from the author's private collection.)

Cleveland's work in Wisconsin began in 1870—just one year after he opened his Chicago office. At this time, the Board of Public Works of the City of Milwaukee authorized Cleveland, whom the *Milwaukee Sentinel* called "... an eminent landscape gardener whose works are all over the country ..."[9] to prepare plans for a new park in the Seventh Ward, on the city's east side.

His design for Juneau Park, named after Milwaukee's founder Solomon Juneau, was submitted on October 15, 1870, along with lengthy and thorough instructions explaining how the park was to be constructed. The entire communication was of such popular interest that several days later, it was printed in full in the *Milwaukee Sentinel*.[10] The article reflected Cleveland's expertise in implementing all aspects of the project.

The site for this important park consisted of a strip of narrow, steep terrain encompassing the bluff and shoreline along Lake Michigan. Cleveland's plan called for a simple, restrained design that respected the area's indigenous natural features. He noted that

"... the position and character of the tract ... confine the whole scope of its possible decoration ... and yet its features are so peculiar, and comprise so much that is picturesque ... that no artificial ornamentation was required, beyond the simple development of their natural character."[11]

His design provided for a roadway at the top of the slope flanked with rows of trees and a sidewalk paralleling the upper edge of the bank. At convenient points, informal meandering paths of varying grade and width descended the bluff. Where the slope was favorable, small level landings were to be constructed to accommodate rustic seats. The natural ridges and hollows on the face of the cliff would remain almost undisturbed except for the minor changes necessary in building the paths and planting the beds of shrubbery to be located on the ridges to increase their apparent height.

Along the base of the slope, at a distance of about 20′ from the water's edge, a 3′ high protective wall was to be constructed adjacent to a proposed meandering pedestrian promenade. At appropriate intervals, steps would lead down to the beach. Toward the south end of the park, two or three pools of water were proposed, fed by springs flowing from the sides of the bluff.

In arriving at this solution, Cleveland sought to avoid using a costly series of artificial terraces which would be expensive to maintain, would interupt natural drainage patterns and would not fit in with the surrounding natural scenery. As one study of Milwaukee's architectural history put it "... the concern for drainage and shoreline control revealed the advanced ability which Cleveland was able to offer his clients at a time when most landscape gardeners knew little of these issues."[12]

Two years later, in 1872, land for the park was acquired and construction began. However, early in 1900, the adjacent shoreline was filled extensively and the character of the park was greatly changed. Today the park is extremely popular, though with the passage of years, Cleveland's design for the site has been altered to provide for additional landfill, the introduction of the automobile, the construction of a rail corridor and other changes. Historically, it is significant for two reasons: it was Milwaukee's first real park, and it is the earliest example of the work of a professional landscape architect known to exist in Wisconsin.

So progressive and stimulating were Cleveland's planning ideas, that he was frequently sought out as a lecturer. In February of 1872, he was invited to address the Madison Horticultural Society in the Agriculture Room of the State Capitol.[13] The title of his talk "Landscape Gardening As Applied to the Wants of the West," was essentially the same highly-acclaimed address he had given the previous week in both Minneapolis and St. Paul, Minnesota.[14] In it, he emphasized that "... Landscape Gardening, or more properly, Landscape Architecture, is the art of arranging land so as to adapt it most conveniently, economically, and gracefully to any of the varied wants of civilization."[15] This may be the first time that the title "landscape architect" was used in Wisconsin by a member of this new profession. He went on to give special "... reference to the laying out and beautifying of cities, parks, ... and other outdoor features, and decried the monotonous results of the widespread use of the gridiron street plan in city after city. He further emphasized the urgent need for setting aside more park areas to accommodate the extensive urban growth he predicted would occur in the emerging Midwestern cities. At the end of the lecture, the Secretary of the Society indicated his hope that Cleveland would come to Madison again ". . . in a professional capacity, for he knew of no city that nature had done so much for and man so little."[16]

A short time later, in the spring of 1872, the Governor of Wisconsin, Cadwallader C. Washburn, and members of his Park Board, called upon Cleveland to help design the grounds of the newly-constructed State Capitol. The Senate had passed an Act in March of that year which gave the Governor authority to appoint a three-member Park Board to see that the Capitol Park was "surveyed, asthetically designed, laid out and platted, and hereafter improved and beautified in accordance with some fixed plan."[17]

A city-wide controversy on the placement of a fence to surround the capitol grounds had begun before Cleveland was called into service, and he started his work in the midst of the turmoil. The squabble began when Governor Washburn proposed extending the fence surrounding the square out to the edge of the streets. A new sidewalk would then be built outside the fence in the space used for horse and wagon parking. This would narrow the streets, dispel the offensive presence of vehicles and provide a more serene pedestrian environment where citizens could ". . .

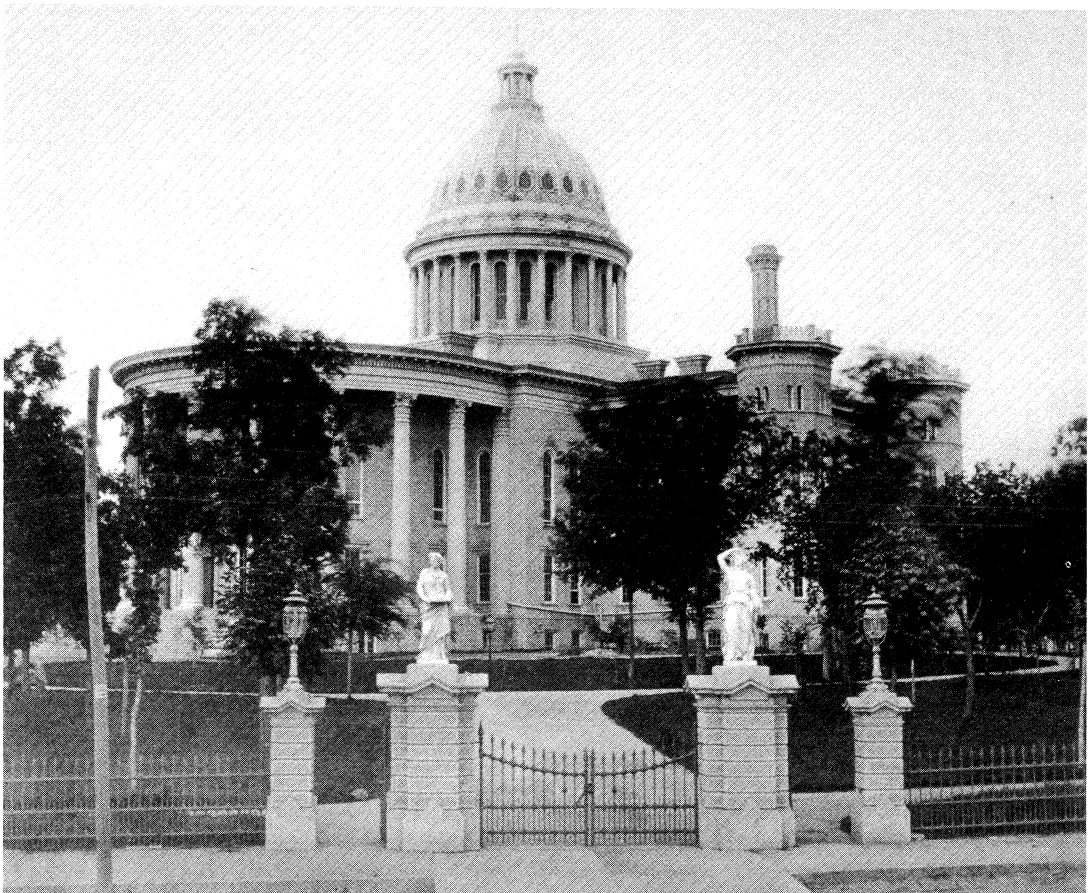

Fig. 2. View of the south-west side of the Wisconsin State Capitol about 1875. The fence and trees reflect the plans and recommendations Cleveland had prepared for the grounds several years earlier. (Photo courtesy Iconographic Division of the State Historical Society.)

escape from the din and turmoil of the streets."[18] After examining the area, Cleveland supported Washburn's proposal noting the ". . . incongruity of an ornamental park surrounded by a stable yard."[19] The following is Cleveland's description of the situation, contained in a letter dated May 1, 1872 to his partner, Wm. French:

"I took the cars for Madison at night and spent yesterday there with the Governor and the committee. The town is or was in a violent state of perturbation in regard to the position of the iron fence and I settled the question in a manner which may subject me to a coat of tar and feathers if I go there again. But I know I am right and they will think so when they see it done and the Governor and committee agreed with me. I have agreed also to furnish a plan of the capitol grounds (12 acres) at $20.00 per acre . . . My visit was a pleasant and gratifying one."[20]

True to his inherent egalitarian beliefs, Cleveland suggested that the capitol grounds become an enclosed park area to be enjoyed by all and separated from the hustle of commercial life on the surrounding square by a see-through Victorian iron fence. His plan showed serpentine walks, a music stand, a summer house, numerous fountains, statuary and urns of flowers and plants. Unfortunately, Cleveland's design was not completely executed. "Only one fountain was built, and the landscaping was confined mostly to trees. Some of the walkways were constructed, but not as many as Cleveland wanted."[21] The square remained essentially a rigidly geometrical setting for the handsome Capital building rather than a "more personalized public space."[22] Ironically, the recent redevelopment of the square captures some of the spirit for the place that Cleveland envisioned well over one-hundred years ago.

Four years later, in August of 1876, President John Bascom of the University of Wisconsin wrote to Frederick Law Olmsted asking him to come to Madison to advise on ". . . the proper position in which we should . . . place our (new) chapel," and ". . . give us suggestions on other points."[23] Regarding other planning for the campus, he went on to say that ". . . we are moving rapidly forward to a first class institution and your work will not be lost."[24] Unable to make the trip to Wisconsin, Olmsted recommended the services of his friend Cleveland ". . . in whose judgement and taste . . . (he had) learned by considerable experience to have much confidence."[25] Unfortunately no correspondence of the University of Wisconsin Presidents before 1886 nor records of the University of Wisconsin Board of Regents between 1867 and 1887 exists. Therefore, it is difficult to verify what became of the chapel building proposal mentioned by Bascom, or whether Cleveland actually worked on the Wisconsin campus. However, Music Hall, originally the Assembly Hall and Library building, was constructed three years later, in 1879, and the possibility of Cleveland's involvement with the site development of this building cannot be ruled out.

Nearly five years passed before Cleveland returned to Wisconsin for another professional commission. In a letter dated November 27, 1881, he stated: "I finished my work last week at Geneva Lake . . ."[26] Another source also briefly notes that he was active in Rice Lake.[27] Both of these commissions were probably for estate grounds.

Although he had as much work as he could handle out of his Chicago office, Cleveland decided to move to Minneapolis. When he left Chicago in the Spring of 1886, this seventy-two year old landscape architect was not moving into retirement, but into his major professional triumph. Here, he helped lay the foundations for the Minneapolis-St. Paul metropolitan park system—perhaps the finest urban open space network in America.

From his new office, Cleveland maintained an involvement with several projects in Wisconsin. In 1887, he was called to Waukesha by Mr. Alfred Miles Jones to lay out the grounds of Bethesda Spring Park—the famous source for medicinal spring water. Jones, a former politician and active entrepreneur, became manager of the area in 1885 and was eager to make improvements so that the Park might become a paying business venture.[28] According to an article in the July 25, 1889 issue of the *Waukesha Freeman:*

"Two years ago . . . (Bethesda Springs Park) was a shady place with good walks and drives, but utterly without system or real beauty. The first thing . . . (Jones) undertook was the better and more tasty arrangement of the park grounds. For this purpose he brought Mr. H. W. S. Cleveland here from Chicago, the gentleman who planned the famous South Park, and this resulted in a complete and systematic survey of the tract . . . (and) a more artistic plan of the shading, drives, walks, and especially of the miniature lake. Facilities were also provided for handsome croquet and lawn tennis courts etc., and right here we may say that the old-fashioned and healthful game of quoits is specially provided for with an apparatus that will no doubt entice many to take it up anew."[29]

After Bethesda Spring Park was rebuilt according to Cleveland's plan, Jones developed it into a popular and profitable recreational spa known widely for the healing qualities of its spring water.

Cleveland's last known work in the State of Wisconsin was in Menomonie in 1892. According to the Proceedings of the Dunn County Board of Supervisors for that year, H. W. S. Cleveland and Son were paid $376.50 for laying out the Dunn County Asylum grounds.[30] The site for this project was entirely barren and Cleveland's plan provided for driveways, footpaths and the planting of some 400 native trees, evergreens and shrubs. An unusual aspect of this project was the appeal he made to farmers in the timbered portion of the county to furnish at least 250 elm, basswood, white ash and box elders from three to five inches in diameter with roots from 15 to 30 inches in length.[31] Cleveland stated "that if farmers would respond to his appeal . . . the asylum grounds would have a selection of trees that could not be excelled."[32]

The most significant surviving feature of his work there is the sweeping entry turnaround in front of the main building. Many of the original trees donated by the local farmers also remain.

In the early 1890's, perhaps because of his advanced age or the beginning of the 1893 financial recession, Cleveland was experiencing a steady decline in work. Yet, he managed to travel to Chicago to see the fruits of his earlier activity in the South Parks and enjoy his friend Frederick Law Olmsted's work at the Columbian Exposition. He later moved back to Chicago, presumably to live with his son's family for his remaining years.

In 1898, his good friend Charles Loring, the distinguished former President of the Minneapolis Park Board, visited Cleveland in Chicago and "found him, in his eighty-sixth year, the same genial, pleasant, unselfish character that he had known for so many years."[33] Loring invited him to write a

Fig. 3. H. W. S. Cleveland during a reflective moment late in his long and productive career. (Photo from the author's private collection.)

paper for the Park and Art Association convention to be held in Minneapolis. Although he at first declined, Cleveland quickly reconsidered and wrote his last article, "Influence of Parks on the Character of Children."[34]

Cleveland died in Hinsdale, Illinois, December 5, 1900, within a fortnight of his 86th birthday. He was buried in Minneapolis, the city he had grown to love.

H. W. S. Cleveland's long and productive professional life spanned almost the entire last half of the nineteenth century. This period, marked by unprecedented urban and industrial growth, produced great changes in the American environment. Perhaps Cleveland's greatest achievement was his ability to foresee this physical change and develop concepts and plans to deal with it in ways that would enrich the lives of countless Americans.

Notes

[1] Other pioneering landscape architects whose work can be found in Wisconsin include: Franz A. Aust, Annette Hoyt Flanders, Henry V. Hubbard, G. William Longenecker, Annette E. McCrea, Frederick Law Olmsted, Jr., Elbert Peets and Ossian Cole Simonds.

[2] H. W. S. Cleveland, *Landscape Architecture as Applied to the Wants of the West,* ed. Roy Lubove (Pittsburgh: University of Pittsburgh Press, 1965), pp. ix-x.

[3] Ibid. 5.

[4] H. W. S. Cleveland, *The Aesthetic Development of the United Cities of St. Paul and Minneapolis* (Minneapolis: A. C. Bauman, 1888), p. 10.

[5] Theodora Kimball Hubbard, "H. W. S. Cleveland: An American Pioneer in Landscape Architecture and City Planning," *Landscape Architecture,* 20 (January 1930), 94. This was the first comprehensive attempt to examine Cleveland's career and shed light on his many contributions to landscape architecture and city planning—professions that both were in their infancy at the time.

[6] Ibid. 94.

[7] Norman T. Newton, *Design on the Land* (Cambridge: Belknap Press of Harvard University Press, 1971), p. 310.

[8] Originally published as H. W. S. Cleveland, *Landscape Architecture as Applied to the Wants of the West; with an essay on Forest Planting on the Great Plains* (Chicago: Jansen, McClurg & Co., 1873).

[9] *Milwaukee Sentinel,* October 19, 1870.

[10] Ibid.

[11] Ibid.

[12] Landscape Research, *Built in Milwaukee* (Milwaukee: 1981), p. 119.

[13] *Madison Daily Democrat,* February 23, 1872.

[14] *Wisconsin State Journal,* February 24, 1872.

[15] Ibid.

[16] Ibid.

[17] John O. Holzhueter, "The Capital Fence of 1872," *Wisconsin Magazine of History,* 53 (1970), 245.

[18] H. W. S. Cleveland, *The Public Grounds of Chicago: How to Give them Character and Expression* (Chicago, 1869), pp. 15-16.

[19] H. W. S. Cleveland, Letter to Hon. C. C. Washburn, July 6, 1872, Olmsted Papers, The Library of Congress.

[20] H. W. S. Cleveland, Letter to W. M. R. French, May 1, 1872, Olmsted Papers, The Library of Congress.

[21] Holzhueter, p. 248.

[22] *The Capital Times,* June 7, 1977.

[23] John Bascom, Letter to F. L. Olmsted, August 24, 1876, Olmsted Papers, The Library of Congress.

[24] Ibid.

[25] Frederick Law Olmsted, Letter to John Bascom, August 31, 1876, Olmsted Papers, The Library of Congress. On the same day Olmsted also wrote to Cleveland informing him of this correspondence.

[26] H. W. S. Cleveland, Letter to W. W. Folwell, November 27, 1881, Olmsted Papers, The Library of Congress.

[27] *The National Cyclopaedia of American Biography,* ed. numerous authors, 63 vols. (New York: James T. White & Company, 1907), V, 540.

[28] *Waukesha Freeman,* October 20, 1898.

[29] *Waukesha Freeman,* July 25, 1889.

[30] *Proceedings of the Board of Supervisors of Dunn County, Wisconsin: Annual Session: November, 1892, and Special Sessions of 1891-2-3* (Menomonie: Flint and Weber, 1893) p. 11.

[31] *Dunn County News,* April 20, 1983. Original source, *Dunn County News,* April 29, 1892.

[32] Ibid.

[33] Board of Park Commissioners of the City of Minneapolis, *Thirteenth Annual Report* (Minneapolis: Harrison & Smith, Printers, 1896), pp. 25-26.

[34] H. W. S. Cleveland, "Influence of Parks on the Character of Children," Introduction by C. M. Loring, *Second Report of the American Park and Outdoor Art Association* (Minneapolis: 1898), pp. 105-106.

THE PUNJAB BOUNDARY FORCE
1 AUGUST - 1 SEPTEMBER, 1947

THOMAS J. AWEN
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On the 8th of May, 1947, the Maharaja of Patiala visited the Viceroy at his palace in New Delhi and voiced the concerns of his people, the Sikhs, concerning the forthcoming partition of their homeland in the Punjab between the Hindus and Muslims. When the Viceroy informed him that there was no way of preventing the forthcoming partition the Maharaja replied:

> Patiala: In that case I greatly fear the Sikhs will fight.
>
> Viceroy: If they do . . . they will have to fight the Central Government; for I and my Government are determined to put down any communal war with a ruthless iron hand; they will be opposed not only by tanks and armored cars and artillery, but they will be bombed and machine-gunned from the air. You can tell your Sikhs that if they start a war they will not be fighting the Muslim League, but the whole might of the armed forces.[1]

So did the last Viceroy of India, Admiral the Right Honorable the Viscount Mountbatten of Burma and cousin to King George VI, promise a terrible response from the military forces under his command. Yet, three months later, as Hindus, Sikhs, and Muslims were killing each other in the Punjab, the group of infantry brigades which formed the Punjab Boundary Force could not fulfill Mountbatten's promise of retribution. Great Britain's failure to ensure a peaceful transition for India from a colony to an independent dominion paved the way for bloody events to come: three major conflicts between India and Pakistan; a bitter religious hatred which includes both Mohandas K. Gandhi (d. 1948) and Prime Minister Indira Gandhi (d. 1984) amongst its list of victims.

What happened? Why did Mountbatten's words count so little in stopping a civil war which left hundreds of thousands of dead and millions of refugees? Why could not the Punjab Boundary Force prevent or at the very least suppress the civil war which destroyed the prosperous Punjab?

The Punjab Boundary Force was the last remnant of the old Imperial Indian Army. The Indian Army in 1947 mustered over 500,000 troops and its existence as a unified force of Hindus, Sikhs, Muslims, and British personnel was threatened by independence and partition. The British element, over 60,000 strong in 1939 would be withdrawn. The British Officer Corp of over 10,000 officers would also leave. Finally, the Muslim contingent, representing 33.8% of the enlisted ranks and 23.7% of the officer corp would be extracted and organized into the new Pakistani Army.[2] Partition meant that a large portion of the army could not be used in any military action until the reorganization was complete. In a paper compiled on the division of the armed forces, the Commander-in-Chief in India, Field Marshal Claude Auchinleck, pointed out that while some infantry battalions and armored regiments were entirely Muslim or Hindu (Sikh included), most were mixed and in none of the formations were all of the officers Muslim or Hindu. All of the units would have to be broken down and gradually rebuilt. His concluding statement made this point: "During the process of division India will be virtually undefended."[3]

India would be "virtually undefended" from any external or internal threat. The only protection India would have consisted of a small reserve of mixed troops to be used in case of emergency. One of those units not communally divided was the 4th Indian (Infantry) Division. The commander was Major General T. W. Rees, and he had been in command for about two years. The division had seen major combat action in North Africa, Italy, and Greece. In late May of 1947, in response to the Governor of the Punjab's pleas for additional troops, the headquaters of the 4th Division and two infantry brigades were ordered to the north. The 4th Indian Division would become the nucleus of the Punjab Boundary Force.

"The whole might of the armed forces" was what Mountbatten had promised to use against the Sikhs should they start civil war. The 4th Division did not represent the "whole might" of the armed forces. However a full strength infantry division would be a powerful arm for the government to use against the violent Sikhs and Muslims. Unfortunately none of the brigades under its command were at full strength. Most of the battalions were at half strength and in the reorganization process the division had lost its British battalions; its artillery contingent had been withdrawn, and both the division's armored reconnaisance regiment and one of its infantry brigades (7th) were omitted from the division's marching orders.[4]

The order of battle, despite the low combat strengths appeared impressive. The Punjab Boundary Force mustered the Headquarters of the 4th Division, the 5th Infantry Brigade, 11th Infantry Brigade, 14th Parachute Brigade, 42nd Lorried Brigade, 114th Infantry Brigade, and the 18th Cavalry Regiment (a tank formation). The five infantry brigades deployed sixteen infantry battalions. They were to police the Punjab, an area with thirty administrative districts of which eleven required "special military measures." The eleven districts alone covered an area of 37,500 square miles with a population of over 14,500,000.[5]

Traditionally, the military was used to supplement, not replace, the civil administration during times of crisis. The massive rioting in Calcutta the previous year had had infantry battalions assisting the police in clearing the streets. The situation in the Punjab was very different from the violence that plagued Calcutta. The population was spread all across the province and while local police corps were responsible for vast areas they were usually understaffed. The police in Calcutta had been reinforced by Gurkha (Nepalese) Gendarmerie and were fairly reliable. The police in the Punjab, who in August numbered over 24,000 constables, began to lose their impartiality under the barrage of propaganda from the various religious communities. Over 74% of the police force was Muslim and as independence approached large bodies of constables began to desert.[6] On the 10th of August, in Jullundar district 7,000 constables fled their posts and demanded safe conduct to Pakistan.[7]

The loss of the police represented the physical disintegration of the civil administration in the Punjab. Troops could not replace police since very few of them were properly trained to arrest or search within the limits set by civil law. Within a week after the first mass desertions by the police (August 14th) the violence in the Punjab changed from peasant armies attacking military units to a campaign of mass terrorism. In the cities, people were being knifed or shot down in the streets or market places. In the countryside, whole villages were burned and scores of bodies littered the ground. The absence of the police meant that troops had to take over safeguarding refugees from attack. The elaborate plans for crushing resistance with the use of tanks and bombers were now irrelevant in stopping the violence.

However, the Viceroy had ordered the

Chief of the General Staff, Lieutenant General Sir Arthur Smith, to send mechanised units to the Punjab:

> ". . . I wished to have tanks, armoured cars, and aircraft used so that the poorly armed insurgent armies would feel that their resistance was futile since they were being mown down without a chance of killing any of the armed forces . . ."[8]

At first, Sikh and Muslim Jathas (battle groups of several hundred or more men) did attack mechanized army units and consequently suffered enormous casualties. In one encounter, an army detachment supported by a tank killed 69 Sikhs, wounded 10 and captured mortars, machine guns, submachine guns, and rifles from the enemy dead.[9] Once the Jathas realized the futility in attacking armored units they stopped, and instead began attacking trains or ambushing refugee columns.

Why were the Sikhs and Muslims killing each other? History reveals that the Punjab, while peaceful during the century of British rule, was a violent region before the British Army arrived in the 1840s. The Mogul Emperors in the sixteenth century oppressed the Sikhs to the extent that their 5th Guru (spiritual leader) led a revolt against the Muslim rulers. Upon his death in 1606, a period of constant war persisted as both faiths fought to achieve martial supremacy. When the Sikhs conquered the Muslims in 1767 their rule was so oppressive that the Muslims in turn rose in revolt. Despite the arrival of the British, religious tensions were exacerbated during the Sepoy Mutiny in 1857. While Muslims joined Hindus in the mutiny the Sikhs remained loyal to the British and had many opportunities to kill rebel Muslims.[10]

A century of peace did not dissipate communal fears as the populations of both faiths (Sikh-Hindu and Muslim) abandoned their homes rather than live under the rule of their new masters. Hindus and Sikhs abandoned over 6.7 million acres of land worth over 5 billion rupees in the West Punjab (Pakistan). Conversely, Muslims abandoned over 4.7 million acres of land worth over 1 billion rupees.[11] The number of refugees, by early October totalled over 8 million people. With the desertion of the police the Punjab Boundary Force had to protect these refugees from attack. Tanks and bombers can make up for any deficiency in numbers when it comes to suppressing poorly armed peasant Jathas. Now the crisis demanded large bodies of troops to protect these refugees. The Governor of the Punjab revealed how weak the P.B.F. had become.

> ". . . I estimated that we should need at least two divisions of full strength and on a War footing—i.e. a minimum of about 20,000 effective fighting men. The effective strength of the P.B.F. is at present about 7,500 or including static troops and training centres about 9,000. . . . Fire power is really less important than numbers."[12]

Sir Jenkins went on the say that neither the railways nor the main roads were safe and that it was impossible to control the village raiding without a great display of force.

Reinforcements were needed: the question was where they would come from. The General Officer Commanding of Eastern Command, Lieutenant General Sir Francis Tuker (and former commander of the 4th Division), sent as reinforcements the 123rd Infantry Brigade (3 infantry battalions), the 1st Mahar battalion, the Headquarters of the 161st Infantry Brigade, and an artillery regiment. Field Marshal Auchinleck also ordered the movement of another infantry brigade and a mixed (tanks and armoured cars) armored squadron to the Punjab but in his report to the Viceroy he stated that no amount of troops could stop the indiscriminate butchery nor could additional reinforcements be sent since the Army was stretched to its fullest extent and it would be difficult, if not impossible to find more troops.[13]

Sikh and Muslim Jathas inflicted considerable losses amongst the packed groups of refugees and every effort to protect them seemed beyond the capacity of the P.B.F. The Intelligence Officer (GSO 1) of the 4th Indian Division, Lieutenant Colonel P.S. Mitcheson, counted between 400 and 600 corpses along a fifty mile stretch of highway and witnessed an ambush against some refugees:

> "In a few minutes fifty men, women and children were slashed to pieces while thirty others came running back towards us with wounds streaming. We got up a tank of 18 Cavalry which killed six Sikh attackers . . ."[14]

Even in refugee columns escorted by troops, refugees (whether Muslim or Sikh-Hindu) were cut down by their attackers. General Rees, in his report described how the Jathas were deployed in ambushing Indian refugees:

> "As the crops were high it was simple to ambush marching columns of refugees. The attackers would remain concealed until the last moment and then pour in a stampeding volley, usually in North-West Frontier fashion . . . In spite of the best efforts of the escorts to hold them together the refugees would scatter in panic; whereupon the ambush parties would dash in with sword and spear. With attackers and attacked inextricably intermingled the escort usually was unable to protect its charges."[15]

It was no safer travelling by train. There were numerous incidents where mobs, as large as 3,000 in number, halted trains and butchered their passengers. Field Marshal Auchinleck reported that over 324 people had been killed in train attacks during the morning hours of the 15th of August. Train crews did not report to duty for fear of losing their lives. Despite the placement of escorts, the mobs would either overwhelm the guards, or worse, the guards would permit the mobs to enter the trains unopposed. On the 22nd of August, the military picket near Khalsa College, Amritsar, and the escort of a Muslim refugee train was overwhelmed by a Sikh-Hindu Jatha. The combined unit (2 officers, 2 NCOs, and 27 enlisted men) expended all of its ammunition before being overrun.[16] All of the refugees were either killed or injured. On the early morning of the 1st of September when a refugee train arrived in Ampala, the escort of 1 NCO and 14 enlisted men permitted a Hindu mob to attack the train. Over 183 people were killed. When the 2/1st Gurkhas[17] arrived, the escort was put under arrest.

A major fear was that communalism would affect the troops of the P.B.F. Apparently it did not occur to high ranking commanders that troops who might have originated from the Punjab were unlikely to remain impartial after seeing their homes burned or their families murdered. Of the troops in the twenty-three infantry battalions in the Punjab Boundary Force: 20% were Sikhs, 25% were Hindu, and Muslims the remaining 55%. Almost all of the Sikh personnel originated from the Punjab and a majority of the Muslim troops were Punjabi Muslims. An officer in a brigade headquarters noted that many Sikh troops had asked for help for their families marooned in Pakistan while many Muslim troops had families trapped on the Indian side of the province. In a telephone report from General Rees on the 11th of August, he reported (optimistically) that the troops were unaffected by the communal tension. Field Marshal Auchinleck did not share his optimism. He commented to Rees' statement, "troops are unaffected" with the question "How Long?"[18] Reports began to arrive at Supreme Headquarters that Hindu or Sikh officers and men were becoming unreliable. It required the direct intervention of British officers before the troops would open fire on mobs of their own faith. Muslim officers and men also become reluctant to shoot their own kind. Open mutiny was considered a serious possibility.[19]

When it became evident that the P.B.F. was no longer an effective military force the Partition Council decided to dissolve the force and allow the armies of both Dominions to accept responsibility for escorting refugees. On the 1st of September, 1947, the Punjab Boundary Force was officially disbanded. The last Indian Army units under British command came under Indian (Hindu) or Pakistani Army control.

The P.B.F. faced major difficulties that were not foreseen by the Supreme Command. Its problems included: Army battalions which were understrength; mechanised units unable to adapt to their new duties; communalism; lack of training to handle police duties. These were major problems that affected the Punjab Boundary Force. How could the Viceroy's Government have acted differently in preventing this disaster?

A larger military force would have eased some problems. The P.B.F. mustered seven infantry brigades, a tank regiment, air and artillery support. It is questionable whether the force reached 55,000 troops but it is likely the conclusion would have been the same. Thousands of troops were needed to pacify the Punjab. Had the P.B.F. and the police been at full strength, they would have mustered 79,000 men (55,000 troops, 24,000 police) to police an area (the eleven districts requiring "special military measures") covering over 37,500 square miles. That would be a ratio of two men per square mile. In comparison, the population of 14,500,000 would average 386 people per square mile. The actual number of troops and police deployed were 17,000 (9,000 troops, 8,000 police) or a ratio of two men per five square miles.

With the disintegration of the police and the collapse of the civil administration the number of troops needed to keep order were immense. To appreciate how understrength the P.B.F. was one can look to another British Colonial post that was plagued by civil war: Palestine. Palestine covered an area of over 8,000 square miles. There were 70,000 troops and 5,000 police guarding the Colonial administration in 1947 and the ratio was nine men per square mile.[20] Yet the Army was unable to suppress the Irgun, the Jewish terrorist army which harassed and bombed the British Government in Palestine. To equal the commitment in Palestine the Supreme Command needed to deploy over 300,000 troops to achieve an equal nine men per square mile ratio.

Did the Viceroy and his council really believe that seven brigades were sufficient to suppress the civil war? Was the Governor of the Punjab negligent in informing New Delhi of the serious situation in the province? On the contrary, Sir Evan Jenkins, the Governor of the Punjab, informed the Viceroy's Chief of staff, Field Marshall Lord Ismay of the need for more troops. Sir Jenkin's army advisor had told him that it would require four operational divisions (i.e. at wartime strength) with an army headquarters to deal with the civil war. The Punjab Boundary Force had seven weak brigades and a divisional headquarters to execute its duties. Lord Ismay felt he could speak for the Viceroy and concluded that the appeal for additional troops had no merit to be reviewed by the Viceroy and it never reached his desk. While Ismay had been Chief of the Imperial General Staff under Prime Minister Winston Churchill, it was the Viceroy and not he who had the last word in any major decision. Still, Mountbatten took no action to countermand Ismay's decision nor was there any record of a reprimand by the Viceroy either in Ismay's memoirs or in Mountbatten's personal log.

Ismay had turned down Sir Jenkin's request for more troops on the basis that there were none available. Great Britain was no longer at war. It is true that Great Britain was war weary and military garrisons were deployed in Palestine and Western Europe but reserves were available. 1947 was a year when troops were withdrawn from occupation duties and reserve battalions from the Territorial Army were demobilized. In Palestine alone, seven infantry battalions and an armoured regiment were withdrawn and returned to Great Britain. Five of those seven battalions were demobilized by October, 1947, after the War Office had ordered all line regiments to demobilize to battalion strength.[21] They were a potential pool of reserves that could have bolstered the understrength formations in India but neither the Viceroy nor his generals considered petitioning the War Office for reinforcements.

There was also the British Army in India. The Army in India was weakened due to peacetime demobilization and while many of the troops and officers were recent conscripts or newly commissioned they represented a formidable military force. According to the accords set by the British Government, the British contingent in India would after 15 August no longer be used in suppressing communal affairs. Thus these troops were available for other duties. The British contingent deployed six independent brigade groups, twelve independent infantry battalions, four armoured regiments, and other support units.[22] Four infantry divisions equal forty infantry battalions, four armoured regiments, and other support troops. The British Army in India plus the reserves from Palestine would have fielded a force of thirty-seven infantry battalions and five armoured regiments. However, the entire British contingent in India and the reserves from Palestine would still not have brought the Punjab Boundary Force to a force of 300,000 troops.

If there was no solution militarily, what other alternatives were available to the Viceroy's Government that could have averted the civil war?

The Sikhs of the Punjab had the most to lose from the partition of their native homeland. They are a small, religious, tribal people who, during the course of history produced disciplined warriors who fought off many invaders. After the British Army crushed the Sikh forces at the end of the 1840s the sons of those earlier warriors enlisted in the ranks of the Imperial Colonial Army to continue the tradition inherent in their religious-military society. With the end of British rule the Sikhs realized that the Viceroy's Government had made no provision to protect their interests in the Punjab. Partition would place over 50% of the province in Muslim hands. Many religious shrines and temples, including the birthplace of their first Guru (teacher) would be defiled by Muslim Pakistani control. The Sikhs responded to this potential blasphemy by waging total war against the Muslims. The Sikhs maintained a small but efficient army which evenly matched the larger but less disciplined Muslim League National Guards. In Amritsar district alone, by 25 August nearly 100 Muslim villages were attacked by Sikhs while only 7 Sikh villages had been attacked by Muslims. In one case a Muslim village of 350 people was attacked by a Sikh Jatha (battle group); there were only 40 survivors.[23] General T. W. Rees commented that the organization of the Sikhs was superior to the Muslim League National Guards and that:

> ". . . both during and after the war there had been heavy smuggling of modern arms into India . . . The Jathas therefore possessed hard cores of skilled fighters armed with rifles, grenades, tommy guns and machine guns. Although the Punjab Mussalmans (Muslims) also possessed firearms and trained men . . . they lacked the cohesiveness of the Sikhs."[24]

Had the Sikhs not been abandoned by the British and had a plan been conceived ensuring that some of the Sikhs' demands could be met the religious hatred might have been mitigated. Throughout the official papers of the Viceroy's Government and including Mountbatten's personal log there is not a single mention of an attempt to assist the Sikhs nor a plan to ease the agony over the partition of their homeland.

Why did not the Viceroy's Government commit the available British Army units in India to the Punjab? The transition of power on the 15th of August meant that British troops were no longer part of the Indian Army, but the Punjab Boundary Force was the last *Imperial* Indian Army force still under direct British control. The P.B.F. commander did not hand over his command to a native Indian (or Pakistani) Army General nor did lower ranking British Indian Army officers relinquish their commands to equivalent native Indian Army officers. The P.B.F. was under the supervision of the Commander-in-Chief in India, Field Marshal Auchinleck, who, in turn, reported directly to the Viceroy. Neither the Hindu Indian nor Muslim Pakistani civilian or military authorities had any jurisdiction over the Punjab Boundary Force. There would have been no problem in placing British troops under P.B.F. control. Why was it not done?

The Chief of the General Staff, Lieutenant General Sir Arthur Smith, issued a secret Army directive dated 29 July 1947 for all British Army officers in command from Battalion level to Army level. No more than sixty British officers ever saw this directive. It dictated that under no circumstances could British Army units be used in suppressing communal riots to save native Indian lives. The only exception was in situations where British lives were in danger.[25] All copies of his directive were to be destroyed and no native Indian Army officers were to gain access to the directive. Both Field Marshal Auchinleck and the Viceroy knew of its existence. Both could have overriden the "no circumstances" policy since they had the authority to commit British troops to the Punjab. While defendants of British policy could argue that it was not proper to shoot one's hosts, i.e. citizens of the new India and Pakistan, at the same time it also meant that the Viceroy's Government would not sacrifice the lives of British troops to save the lives of thousands of their former crown subjects, i.e. the Indians.

The Punjab Boundary Force had to stop the civil war with its own limited resources and without reinforcements. The P.B.F. was sent to the Punjab to support the civilian government of Sir Evan Jenkins. When the government collapsed was it not the responsibility of the Army to assume control of the government and declare martial law? Was Sir Jenkins negligent in reporting the state of the government in the Punjab to the Viceroy?

The P.B.F. was a peacekeeping boundary force, not a group of heavily armed and mechanised police. Neither was it an army of judges, lawyers, or civil servants nor was it ever meant to be one. When the military declares an area to be under "Martial Law" the military judicial system integrates with the civilian judicial system. The reason is that the military judicial system deals with violations of Military Law, not civilian law. While certain rights and privileges under civilian law are suspended during martial law the civilian courts still try and convict civilian miscreants under the established procedures of civil law. Both Sir Jenkins and General Rees advised against the declaration of martial law. In his report of 4 August, 1947, Sir Jenkins wrote:

> "We are not at present dealing with a situation in which Troops can act decisively- . . . There is no short-cut by Civil or by military procedure; for neither a Civil Governor nor a General administering Martial Law can properly shoot innocent people merely because they . . . live near the scene of an outrage."[26]

Martial Law was useless since without an existing civilian court system there was no way for military officers to legally convict and sentence people for crimes that were not applicable under Military Law or nor to establish criteria for criminal convictions that met civilian requirements.

If martial law could not be declared then how could the Punjab Boundary Force deal with the civil war? Did not the Governor, Sir Evan Jenkins, inform the Viceroy of the impending collapse of the government? Indeed, he had informed the Viceroy that not only the civilian administration was collapsing but also that the police was becoming scandalously corrupt and negligent, and discipline was disintegrating. The courts were unable to convict felons since magistrates refused to sentence law breakers of their own faith. This report was sent to the Viceroy on the 25th of June, 1947. Mountbatten had five weeks to prepare for the upcoming state of chaos and yet nothing special in terms of orders or personnel was prepared to counter the collapse of the civilian government.

A prosperous province was laid waste and old religious hatreds were reawakened in a civil war which brought nothing but death and destruction to its inhabitants. While the victims were Indian, key Government leaders were British. The Viceroy, most of his staff officers, most of the provincial governors, and all of the Senior Army officers were British. With the withdrawal of British sovereignty these people no longer had a future in the new India or Pakistan. Mountbatten personified that feeling. Mountbatten had been anxious to set a time limit in his appointment since he feared that he would lose seniority by his appointment to India and that being the last Viceroy would not count favorably towards promotion.[27] Over 10,000 British Indian Army officers, 1,600 British Indian Civil Service officials, and 50,000 civilians faced a future in which Indians, not British, would be the rulers. Very few were willing to be part of the new India's future. Sir Evan Jenkins, in his report to the Viceroy dated 16 April, 1947 read:

> "Every British official in the I.C.S. and I.P. (Indian Police) in the Punjab including myself, would be very glad to leave it . . . no British official intends to remain in the Punjab after the transfer of power. Six months ago the position was quite different"[28]

The civil war had a major influence in the decisions of these men, but the feeling was similar in the British Officer Corp. Out of 11,400 officers in the pre-partition Army, 8,200 were still serving in the ranks by Independence. Yet fewer than 2,800 volunteered to remain with their units in the new Indian and Pakistani Armies. Many of these officers could not accept the lack of a British Indian Army.[29]

Mountbatten personified the withdrawing British by his lack of proper direction, organization, and preparation in the creation of the Punjab Boundary Force. Mountbatten's failure to deal with the Sikhs meant that there was no peaceful option to prevent the civil war. Mountbatten's failure to assert his privilege as Viceroy and countermand the secret Army directive forbiding British troops to save Indian lives crippled the P.B.F. in its attempt to find reinforcements. Defenders of the Viceroy may argue that the P.B.F. was no longer under British Army control but that argument is invalid since the evidence indicates the P.B.F. was still under British, not Indian or Pakistani, control.

The Punjab Boundary Force was not a special army that was sent to reinforce the formations already in the Punjab. Rather, it was a title conferred on formations already deployed in the Punjab. There was no consideration concerning the religious composition of the troops, the weak formation strengths, the imminent collapse of the Punjab Government, nor contemplation of an alternate plan in mustering army reinforcements for the Punjab (aside from mobilising the British Army units in India). Proponents defending the Viceroy could argue that Mountbatten did not know of the situation in the province nor have any control in the Boundary Force's mandate. However, the evidence suggests otherwise. Mountbatten was updated every week by the Governor and he personally visited the devastated areas. The intelligence was accurate, its analysis of the forthcoming violence precise, but the Viceroy's Government chose to ignore or reject it.

The civil war in the Punjab was perhaps unavoidable but the British Government did little to mitigate the consequences. Instead of preparing for the worst in the Punjab, Senior Government and Army officials were concerned about the unknown future that lay before them. It was understandable that to have one's career swept away by Independence was traumatic but these men forgot one important thing: their duty. Their negligence permitted 8,000,000 people to become refugees and over 200,000 (some estimates total 600,000) people to lose their lives. Perhaps no sizable body of troops could have suppressed the civil war, but the Viceroy and his generals did not attempt to find additional reinforcements (e.g. from Britain). Instead they did only what was absolutely necessary in crushing the civil war. Unfortunately it was not enough to mitigate the tragedy in the Punjab nor prevent the failure of the Punjab Boundary Force.

NOTES

1 Nicholas Mansergh, *The Transfer of Power in India 1942-1947.* (Her Majesty's Stationary Office, London, 1981, Vol. X), 686.

[2] Lorne J. Kavic, *India's Quest for Security.* (University of California Press, Berkeley, 1967), 82.

[3] Nicholas Mansergh, *The Transfer of Power in India* 1942-1947. Vol. X, 1008.

[4] G. R. Stevens, *Fourth Indian Division.* (Mclaren and Son Ltd., Toronto, 1948), 403.

[5] Ibid., 405.

[6] S. Gurbachan Singh Talib, *Muslim League Attack on Sikhs and Hindus in the Punjab 1947.* (Shiromani Gurdwara Parbandhak Committee Amritsar, 1950), 73-74.

[7] G. R. Stevens, *Fourth Indian Division*, 408.

[8] Nicholas Mansergh, *The Transfer of Power in India* 1942-1947. Vol. X, 828.

[9] Ibid., Vol. XII, 704, 735.

[10] H. V. Hodson, *The Great Divide.* (Hutchinson of London, London, 1969), 18.

[11] Penderel Moon, *Divide and Quit.* (Chatto & Windus, London, 1961), 270.

[12] Nicholas Mansergh, *The Transfer of Power in India 1942-1947.* Vol XII, 702.

[13] Ibid., 737.

[14] G. R. Stevens, *Fourth Indian Division.* 408.

[15] Ibid., 406.

[16] Francis Tuker, *While Memory Serves.* (Cassell, London, 1950), 483.

[17] 2nd Battalion, 1st Gurkha Rifles (Regiment).

[18] Nicholas Mansergh, *The Transfer of Power in India, 1942-1947.* Vol. XII, 667.

[19] Francis Tuker, *While Memory Serves.* 448-449.

[20] Gregory Blaxland, *The Regiments Depart.* (William Kinger, London, 1971), 49.

[21] Ibid., 8.

[22] Ibid., 20.

[23] SIKHS' "JUST RIGHTS," *The Times* (London), (August 27, 1947), 4.

[24] G. R. Stevens, *Fourth Indian Division.* 406.

[25] Nicholas Mansergh, *The Transfer of Power in India 1942-1947.* Vol. XII, 625-626.

[26] Ibid., 526.

[27] Michael Edwardes, *The Last Years of British India.* (World Publishing Co., Cleveland/New York, 1963), 156.

[28] Nicholas Mansergh, *The Transfer of Power in India 1942-1947.* Vol. X, 283.

[29] H. V. Hodson, *The Great Divide.* 416.

THE GREEK DOCTRINE OF ETHOS MANIFESTED IN THE PYTHAGOREAN AND EQUAL TEMPERAMENT INTERVALS IN THE TERTIAN HARMONIC SYSTEM OF THE TWENTIETH CENTURY AND SOME SOCIAL IMPLICATIONS

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Since music is an eternally present mode of human expression, it follows that certain factors which governed the human response to music over 2,000 years ago may still be operable today given the premise that both music and man are the result of particular natural phenomena with some common origins.

It is part of the theoretician's task to explain not only the conventions and practices inherent in music but to examine and explain the origin, logic and paideutic reasons for them. If the following ideas seem to develop into a tacit defense of the tertian system, it should also be borne in mind that there is no implicit rejection of any other system.

The fact that one can rarely turn on a radio randomly tuned at any time and hear anything but music consisting of melodic and harmonic material derived from the most traditional tonic and applied dominant tertian sonorities, seems to indicate that there may be some cosmic or at least terrestrial physical phenomenon governing this state of affairs. Notwithstanding the existence of a few stations specializing in the classics or the esoteric, the preponderant musical fare traveling the air waves is tonal and based on the system derived from Zarlino's "harmonia perfetta" further refined and codified by Rameau's fundamental bass and theory of invertibility and subsequent functional harmonic principles.

The Pythagorean ratios and consequent intervals were known long before the harmonic age, and it is a curious fact that it took so long, nearly 2,000 years for the tertian system to evolve and assert itself as the predominant organizing factor in harmonic structure.

A possible reason for the late emergence of harmonic polyphony was the fact that the ear of the ancient musician seemed to be much more perceptive of subtle melodic variations, variations consisting of all the possible combinations of melodic intervals within the Greek Greater Perfect System of a 15 tone-2 octive diatonic sequence. Some of these intervals may have been lost to modern usage. Other authorities on Greek music state that the tones within the tetrachord could be fixed by any one, two, or three of an infinite number of intervalic possibilities and while Pythagoras advocated the fixing of these intervals by mathematical proportion, Aristoxenus asserted that the *ear* should determine the proper placement. Nonetheless, with the infinite number of *melodic* possibilities available, perhaps the ancient ear was not seeking additional complexities of sound.

The Greek modes, while still not very well understood by contemporary musicologists, seem to have been constructed from sets of intervals which were not arbitarily determined but were derived from observable, or rather, experienced phenomena. It can be reasonably assumed that the interval encompassing the tetrachord of the Greek system was easily derived from and observed as the ratio 4:3 since this interval can easily be produced by damping a vibrating string at appropriate nodes i.e., the second and third which produce the third and fourth partials of the overtone series.

It is still not certain if the whole and half-tone intervals within the tetrachord were the 9:8 and 16:15 ratios we use today in the diatonic system. That the intervals used were probably derived from the upper partials seems reasonable.

Although the production of partials above the 9th, 10th, 12th and 16th are difficult to produce on a single string, it is probable that the smaller interval, the 16/15 ratio semi-tone, was accepted as a logical extension of the series. It also was needed to complete the sequence of proportions necessary to the perfect octave.

Much has been written about the supposedly vast differences between the harmonic conventions of western music and those of other cultures which do not share the use of the tonic-dominant tertian system. However, these differences are not so great as they seem when it is taken into account that many of the so-called microtones and intervals less than the 16:15 semi-tone are actually inflections, or a sort of musica ficta, as it were, and embellishments of a subtle nature too slight to lend themselves to precise notation. Certain oriental instrumental music while employing a rather diverse set of scale intervals at the same time uses drone string accompaniment of perfect 5ths and major thirds.

To think that the tonality of the tertian system has run its course and is ready to give way to a new atonality or new tonal system is to deny the cosmic nature of the harmonic series and man's natural response to it, whether he understands it or not.

The acceptance of the perfect 5th as the first harmonic interval (the octave not qualifying as an harmonic interval since it does not progress) appears to be the result of the universal nature of its occurrence in the harmonic series. The series will occur in a string set in motion in Siam, Bangkok, and Calcutta in precisely the same way it will in Madrid, Berlin, or Chicago. Its cosmic nature is as certain as that of the color spectrum which will result when light is passed through a prism in the orient or the occident.

Vocal music of primitive cultures employs intervals of the harmonic series through the sixth partial quite extensively and perhaps was doing so at a time when the polyphonic composers of the 13th and 14th centuries were still reluctant to allow the 5:4 major third to occur in a final cadence. Why were composers so long in accepting these consonances and why was tertian homophony so long in arriving? And since its arrival and full acceptance in the 16th century why was there such an active movement to reject it in the early 20th century?

There are in use throughout civilization intervals of the major and minor third for practical applications. Consider the train whistle and the auto and truck horn. These devices are usually tuned to a major or minor third, never a perfect 5th or 8th. The sound of the WW II CD warning siren was distinctive for its minor third interval. Why not an augmented 4th? Certainly the dissonance of this interval would have carried a note of alarm. However, the affinity of the human ear for the third interval seemed to give it a priority over the more dissonant interval even for such drastic uses.

Natural tonality needed some adjustment in the 17th and 18th centuries, not because there was anything inherently wrong with it, but because of the limitations of the keyboard in accommodating a circle of pure fifths. A vocal ensemble singing perfectly in tune starting in the key of A and modulating through the eleven remaining keys through a circle of absolutely perfect fifths will, upon returning to the key of A, be only 6 cps sharp (446/440). This translates to only ½ a cps per key and few pieces progress through more than 3, 4, or 5 in the standard repertoire. Many choral directors would be happy if their choruses, performing a lengthy work modulating through three keys ended up within 1½ cps of the starting pitch on page one. Given the differences between individual tone quality and vibrato of most voices in a mixed chorus, this discrepancy is hardly noticeable. (and, it might be added, preferable to *some* vibratos) Disregarding for the moment the practical discrepancies of the pure and tempered intervals, there is room for consideration of the harmonic series on the basis of its universal appeal to the human ear. The first eight partials of the series contain the essentials of the tertian system. The primary harmonic progression I-IV, V-I, IV-V, embody the logic contained in the return to the fundamental of the third and fourth partials, second and third partials, and the 7th and 8th, although the stepwise progression IV-V is not precisely the 8:7 ratio but rather the 9:8. However, it *is* possible that the tertian system is not as closely linked to the diatonic major scale as is customarily thought. The diatonic scale is derived and constructed from the series in a manner which suits its own melodic purposes. But, the triad 4:5:6—the harmonia perfetta, is inherently logical, being an integral and contiguous part of the series, and hence, its universal appeal.

The ethos of Greek music was exclusively related to melodic structures and never to the harmonic aspect since, to the best of our knowledge, all music of the period was monophonic. More specifically, melodies of Greek music supposedly each had their own peculiar ethos or power to act upon man's sensibilities in such a way as to affect his character or ethical behavior. To what *extent* a person was thought to be affected or simply emotionally responsive is not altogether clear, although the *manner* in which they were affected was carefully defined.

The ethos of a melody was dependent on three factors: mode, genus, and rhythm. In our time, it seems that another factor, harmony, enters the picture. One should probably not discount one other factor which has crept into the picture in the decades since WW II—electronically induced volume, a dimension which, in many instances, tends to obscure melody, harmony, and rhythm and may even have an ethos of its own.

Now if we are to ascribe ethos to any of the musical sounds of the contemporary scene we should isolate those musical sounds which seem to be most natural, or the result of natural phenomena rather than those which have been contrived, since Greek melodies were constructed from supposedly natural scales—or at least scales derived from natural proportions.

The scales of Didymus, Pythagoras and Ptolemy are all derived from certain proportions and ratios found in the harmonic series but none of them are from a sequence of *contiguous* tones in the series. Consequently, the ear seems not to perceive these as natural as the triad since the triad *does* occur in natural contiguous order.

The acceptance of harmonic intervals occurred chronologically in precisely the same order as their occurrence in the series. If this process continues, and there is no reason to believe it will not, intervals smaller than the minor 2nd may become accepted as harmonic as well as melodic intervals.

A composition in traditional tertian harmony is now thought of as in one or the other of the only two harmonic modes left to us in popular use; major and minor. Melodic structures are born of these two primary tonalities and the three forms of the minor mode available to us do little to effect the overall harmonic impact of minor sound. That is to say, the triads derived from the different modes are identical. The minor triad cannot be found in the series at *all* in *contiguous* form, only by omitting certain tones 10-(11)-12-(13-14)-15, etc. Therefore, it might be thought that the minor triad is more a child of a contrived scale than an integral part of the natural series.

Redfield, in "Music: a Science and an Art," says, "for purposes of melody alone, it is probable that one scale is as good as another—and the various scales that have arisen at different times the world over prove conclusively that the human ear can learn almost any kind of scale."

Consider the probability of a scale such as the one in figure 1 resulting from the experiments of a fictitious ancient musician.

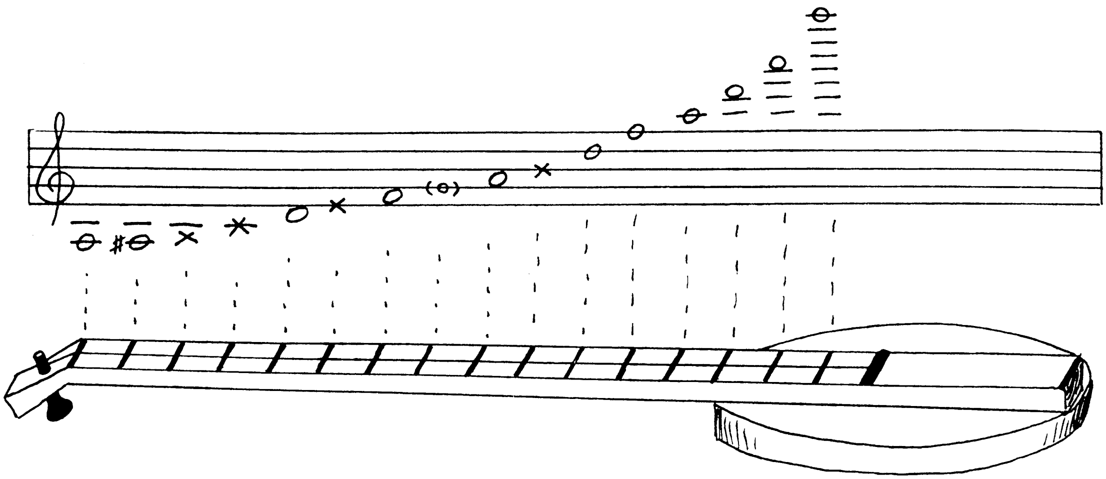

Fig. 1 The ancient thrmbl

Given man's predilection for symmetry in other art forms, it seems not improbable that someone at some time attempted constructing a scale or sequence of tones for melodic purposes by this method of equipartition.

Kathleen Schlesinger discussed scales of equipartite spacing in "The Greek Aulos," published in 1939. For the purposes of this discussion, a fretboard on a single stringed instrument serves as an example.

Stopping the string on frets spaced *equal* distances apart produces certain tones which can be used in our present diatonic system and some that cannot. It is also apparent that such a spacing produces a series which is *identical* to the *natural* series; but inverted! It is also apparent that the *minor* triad occurs here contiguously. Could not some theorist, a counter-part of Zarlino's, say, studying this series, have declared the *minor* triad the "harmonia perfetta" on the ground that it *does* occur in a natural sequence of tones in this inverted series? That someone did not is probably due to the fact that an equipartite spacing does *not* produce a *natural* series, a natural series always generating from the fundamental, and *only* occurring in a medium left to freely vibrate in a manner not affected by outside influences (such as arbitrarily placed frets.)

The question now arises: what can the discrepancies between equal temperament intervals and pure intervals have to do with ethos, if indeed there is any such thing, in this day and age?

In the first place, few people today are aware of the sensations of pure intervals. Nearly all popular and commercial music is heard in conjunction with keyboard harmonies and a great deal of the concert repertoire is associated with equal temperament. In fact, there are so few opportunities to hear purely tuned intervals that the listener must rely on other dimensions for the ethos experience.

Some of the discrepancies existing between equal temperament and true porportional tuning can be seen in figure 2. The 16/15 Pythagorean semi-tone cannot be used to construct a chromatic (12-tone) scale. Nor can the 9:8 whole tone.

There does not appear to be a name for the discrepancy between the octave derived from twelve 16/15 semi-tones and a pure 2/1 octave. Since the difference between four perfect fifths and two octaves plus a major third is distinguished by the name "comma of Didymus," perhaps this other difference could be called the "comma of La Crosse," or "West Bend," the discrepancy being greater than that of Didymus and therefore deserving of a name.

At any rate, singing an ascending chromatic scale starting at A220 and continuing through 12 pure 16/15 semi-tones will result in an octave nearly 1½ semi-tones sharp. We do much better with the 9/8 whole tone scale, the resulting octave in this case is identical to the octave derived from the circle of pure fifths, 6 cps sharper than A440.

It seems the closest we can come to a 12-tone chromatic scale within an octave using true natural proportions is to use the 18/17 semi-tone. This, however, gives us something short of a perfect octave. Curiosity compelled the investigation of a proportion which would come close enough to give a semi-tone accurate enough to produce a true octave—or at least one true enough to have practical use—the result was a highly impractical 180,000:169,897 giving a factor of 1.0594654 (23 ten millionths greater than $12\sqrt{2}$).

Certainly the tables in figure 2, with the exception of the last column, are familiar to everyone. The similarities and discrepancies between the other columns have been dealt with many times.

The point of these observations is that since ethos was manifest in modes and intervals of pure and natural origin, then it should *presently* be manifest in phenomena of natural origin. In spite of the fact that triads of the tempered system are no longer pure, they still originate from—that is—their tertian *essence*—originates from a purely natural phenomena.

If music is to merely *reflect* man's condition, then we need not be concerned with its ethos at all. On the other hand, if it is to exert some manner of influence, then should it not embody that essence most likely to result in an ethos to which man—listeners—might respond?

Hindemith felt that music should be *used* —that is—serve some purpose other than that of being performed in an esoteric vacuum—Gebrauchs musik.

This requirement necessitates the use of a recognizable harmonic vocabulary. He fur-

	16/15	17/16	18/17	$\sqrt[12]{2}$	9/8	7/6	6/5	5/4	3/2	Ptolemy	Didymus	Equipartite
A	220	220	220	220	220	220	220	220	220	220	220	220
A#	234.66	233.75	232.94	233.08					234.93	9/8	9/8	234.66
B	250.31	248.36	246.64	246.94	247.5				247.5	247.5	247.5	251.43
C	266.99	263.88	261.15	261.63		256.66	264		264.3	10/9	10/9	270.76
C#	284.79	280.37	276.51	277.18	278.44			275	278.44	275	275	
										16/15	16/15	
D	303.78	297.9	292.78	293.66					297.33	293.33	293.33	293.33
D#	324.04	316.52	310.00	311.13	313.24	299.44	316.8		313.24	9/8	9/8	320.00
E	345.64	336.30	328.23	329.63					330	330	330	
F	368.68	357.32	347.55	349.23	352.4			343.75	352.4	10/9	9/8	352.
F#	393.26	379.65	367.99	369.99		349.35	380.16		371.25	366.66	371.25	
G	419.48	403.38	389.64	392.00	396.45				396.45	9/8	10/9	391
G#	447.44	428.59	412.55	415.31					417.66	412.5	412.5	
A	477.27	455.37	436.82	439.99	446.003	407.57	456.19	429.68	446.003	440	440	440
A#				466.16								
B				493.88								502.8
C				523.25								
C#												
D												586.66
											F	704
											A	880
											D	1173
											A	1760
											A	3520

Fig. 2

ther asserted that *tonality* was as inevitable as the law of gravity.

Composer Lou Harrison's philosophy is in the motto "—the overtone series is the rule—world music is the font."

Robert Baksa, in the Musical Heritage Review makes several rather sensible statements: 1) as a language, the tonal system allows a *wide* range of expression; 2) some composers who would prefer to work with traditional materials and harmonic vocabulary, avoid doing so because they accept, as fact, statements that older traditional, conventional methods, systems and tonalities have been totally exhausted—and finally; 3) he is convinced that after 25 years of composing, only a *little* cleverness is needed to come up with a convincing experimental piece—but to write a memorable work within traditional means calls upon a much more intense level of creativity.

Composers who have at their disposal musicians of professional caliber to perform their works have a factor working for them which has little to do with the tonal system they may have chosen for an experimental piece. Certain instrumental and vocal tones can be of such inherent beauty that combinations of tones having nothing to do with natural proportion have an appeal based on the *quality* of the tones alone and not their tonal relationships.

Webber's recently televised "Requiem" received widely divergent reviews—some positive—others negative—but aside from the merits of the work itself, it seems to this listener that *any* composition would have seemed to have merit based simply on the quality of sounds produced by the assembled musicians of world-class caliber.

The infinite possibilities *outside* the tertian tonal system present the composer with such freedom that it requires considerable discipline to set some limitations and boundaries in order to know where one might intend to go. On the other hand, the very *limitations* of tonality help assign *some* boundaries and *challenge* the composer to say something profound in a language that more than a handful can understand—let alone enjoy. If the contemporary composer sincerely wishes to say something to a listening world—would it not be well to say it at least part of the time, in the mother tongue, so to speak.

Without a doubt, there are valid, naturally generated principles waiting to be discovered and upon which new tonalities and techniques will be built—and there still is a lot to be said which has remained unspoken—in the language we already know so well—and with an ethos—however misunderstood—all its own.

IS THERE A MORAL DIFFERENCE BETWEEN ACTIVE AND PASSIVE EUTHANASIA?

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The purpose of this paper is to answer the question whether there is a moral difference between active and passive euthanasia. So long as a competent, informed, adult patient has requested it, does it matter whether what he has requested is active euthanasia instead of passive euthanasia?

Certainly institutionalized, traditional medical ethics holds that there is a difference between active and passive euthanasia. For example, the American Medical Association's House of Delegates has issued the ruling that "The intentional termination of the life of one human being by another—mercy killing—is contrary to that for which the medical profession stands and is contrary to the policy of the AMA (House of Delegates, 1973). The opposition to active euthanasia in medical ethics goes back much further than the AMA. When the physician pledges the Hippocratic oath he promises that "I will neither give a deadly drug to anybody if asked for it nor will I make a suggestion to this effect."

It is interesting to note that these uncompromising stands against active euthanasia may be lagging somewhat behind important shifts in public opinion. A series of Gallup organization surveys between 1950 and 1973 asked the question "When a person has a disease that cannot be cured, do you think doctors should be allowed by law to end the patient's life by some painless means if the patient and his family request it?" In 1950 60% of respondents thought that the doctor should not be allowed to fulfill the patient's request whereas 40% thought that he should. Twenty-three years later the distribution of opinion had flip-flopped, so that in 1973 only 43% believed that physcians should not have that discretion, while 57% thought that the physician should be allowed to end the patient's life by painless means (Public Opinion, 1983). Within society as a whole there is clearly a sharp division of opinion about the relative acceptability of voluntary active euthanasia.

So is there "a moral difference" between active and passive euthanasia? First of all we have to be clear about what question we are asking. One way of getting clearer about that is to be clear about what kind of answer we may be looking for. There are two kinds of "NO" answers that might be given. The first kind of "NO" answer would say that active euthanasia and passive euthanasia are "morally equivalent." That is, in any situation in which passive euthanasia would be justified active euthanasia would be justified also, and vice-versa.

The other kind of "NO" answer that might be given to the question is to say that there is no moral difference between active euthanasia and passive euthanasia that can justify permitting the use of passive euthanasia, but absolutely prohibit the use of active euthanasia. In this second sense of the question we are asking a question about policy: whether the current policy absolutely prohibiting active euthanasia can be morally justified.

When I ask the question whether there is a moral difference between active euthanasia and passive euthanasia I will be asking it in the second of these two senses. I will be focusing on this second sense for two reasons. First of all the claim of moral equivalence of active and passive euthanasia is probably false, since we can readily think of circumstances under which passive euthanasia would be justified, but active euthanasia would not be. For example, we might imagine a patient who while competent made a clear request for some form of passive euthanasia. She subsequently lapses into unconsciousness from which she will not recover. Perhaps the patient asked that she not be put on a respirator under certain circumstances. Such a request might well justify a decision to withhold the respirator under the circumstances specified by the patient. But the administration of active euthanasia would not thereby also be justified. The patient might, for example, have strong religious objections against "mercy killing," in which case the administration of active euthanasia would be an affront to her values. The other problem with the first sense of the question is that it does not directly address the social policy that aims to allow some forms of passive euthanasia but absolutely prohibits active euthanasia. Certainly if it were true that active and passive euthanasia were morally equivalent, it would follow that we could not justify a policy that allows one but prohibits the other. But if active and passive euthanasia should turn out *not* to be morally equivalent in the sense that I have described, it does not follow that the policy of prohibiting one but allowing the other is morally or socially justifiable. For example, it might be argued that active and passive euthanasia are not "morally equivalent" because active euthanasia offers opportunities for abuse—only active euthanasia can be abused by killing healthy people who don't want to die (More on this argument later). But even if this is true, it doesn't follow that it is impossible to develop an acceptable policy permitting active euthanasia. All that follows is that it will have to address some additional concerns than those dealt with by the current policy permitting passive euthanasia.

In what follows I will want to argue that there is no systematic moral difference between active and passive euthanasia that will justify allowing some acts of passive euthanasia, but at the same time prohibit all acts of active euthanasia. To show that I intend to use the following strategy.

The first step in the strategy is to establish that if there is a moral difference between active and passive euthanasia, then acts of active euthanasia must meet two conditions: *Condition* 1. Acts of active euthanasia must have some characteristic not shared by acts of passive euthanasia. Clearly, if active and passive euthanasia were exactly alike in all respects there could be no justification for taking a different moral or social attitude toward active euthanasia. If we continued to have a different attitude, it would be a difference for which no reasons could be given. Our rejection of active euthanasia would then have the character of a superstition or taboo. *Condition* 2. Such a unique characteristic of active euthanasia must imply a significant moral difference between the two. The reason for this second condition is to rule out the use of morally irrelevant or insignificant differences. A hyperbolic example of this would be if someone were to claim that the difference rested on the fact that active euthanasia was abbreviated AE and passive euthanasia was abbreviated PE. This is a difference that satisfies the first condition, but it is not a morally significant difference that would justify a different social policy on one than on the other.

If these two conditions are accepted (I won't argue for them any further), then the second step in the strategy is to show that none of the reasons which have been given to justify the prohibition of active euthanasia meet both conditions. If this can be accomplished, then we will have all the steps of an argument which shows that there is no moral difference:

1. If there is a moral difference between active and passive euthanasia, then conditions 1 and 2 must be met.
2. Conditions 1 and 2 cannot be met

(none of the reasons put forward satisfy both conditions).

3. Therefore, there is no moral difference between active and passive euthanasia.

It should be noted that this is an "open-ended" form of argument, since not every possible difference can be canvassed. In the remainder of the paper, I intend to describe some of the arguments that have been offered for making the distinction between active and passive euthanasia and show why they fail the conditions that I have set forth.

Probably the argument that's offered most frequently points out that passive euthanasia is "letting die" whereas active euthanasia is active "killing." Since it is always wrong to kill an innocent human being, active euthanasia but not passive euthanasia must always be wrong.

I think that this argument meets condition 1 but not condition 2. This can be demonstrated using an example provided by James Rachels (Rachels, 1975). Rachels describes two evil uncles named Smith and Jones. Each of these uncles has a young cousin and each of the uncles stands to gain a considerable inheritance if the young boy suffers an unfortunate accident. Each of the evil uncles therefore forms the intention of drowning the child when he is taking his bath. And each of the evil uncles enters the boy's bathroom fully intending to hold his head under water until he drowns. The one evil uncle Smith goes into the bathroom and forces the child's head under water until the child dies from drowning. The second evil uncle Jones enters his cousin's bathroom with the same intention, but just as he walks in the door the young boy slips on a bar of soap and hits his head on the side of the tub so that he is knocked unconscious. Since this fits in very neatly with Jones' plans he just stands by, does nothing, and lets the boy drown.

As Rachels points out there is a difference between what Smith and Jones did. What Smith does is an active killing but what Jones does is a passive letting die. But Rachels asserts—and I agree—that that makes no difference to our moral evaluation of Smith and Jones. We think that what each of them did is equally reprehensible. The bare fact that one is a "killing" does not make it morally worse than the other and the bare fact that the other can be described as a "letting die" does not make it less morally objectionable.

The example is not an attempt to draw a direct analogy between what Smith or Jones did and what doctors do when they allow passive euthanasia. Doctor's intentions are almost always more benevolent. All that the example is intended to show is that the distinction between killing and letting die is by itself not a reliable guide to what's morally justifiable or defensible. If indeed the example shows that this distinction is not a morally reliable one, then we should not use it uncritically to try to mark a moral difference between active and passive euthanasia. There must be some other difference beyond the bare fact that one is a killing and one is a letting die if indeed we are to justify our different moral attitudes toward active euthanasia.

This leads me to a second argument which is sometimes brought forward to articulate a bit more what the difference is between killing and letting die in the medical context. When we let a patient die, it is said, it is the disease or the condition that is the cause of the patient's death and so the physician is not responsible for the death in the same way that he or she would be if death were caused by a lethal injection (as in active euthanasia).

This argument meets condition 1, but not condition 2: if this identifies a difference, it is not a morally relevant difference. Even if we admit that there is a difference in the "causes" of the patient's death this cannot show that passive euthanasia is permissible whereas active euthanasia is not. This conclusion would follow only if we equivocate with the word "responsible." The following argument is an example of how this equivocation works.

(a) When a patient is allowed to die it is the disease that is $responsible_1$ for his death.
(b) When the disease is $responsible_1$ for the death, then the physician is not $responsible_2$ for the death.
(c) Therefore when the patient is allowed to die (passive euthanasia), the physician is not $responsible_2$ for the death.

In the first premise of this argument the word "responsible" is being used as a synonym for "causes." This use of the word "responsible" is morally neutral, just as it's morally neutral in the sentence "spontaneous combustion was 'responsible' for last night's fire." However, when we get down to the conclusion of the argument, the word "responsible" is not being used in a morally neutral way and is not being used as merely a synonym for "causes." "Responsible" in the conclusion is a synonym for "blameworthy." The only way we can link these two distinct senses of "responsible" is by the use of a claim like premise (b). But such a claim is clearly false. Cases of gross negligence by physicians would be an example in which the disease or underlying lethal condition was the cause of the patient's death and yet in those cases the physician would remain blameworthy for that patient's death. The fact then that in passive euthanasia the disease rather than the physician is the immediate cause of the patient's death does not by itself provide us any grounds for relieving the physician of moral responsibility and certainly cannot provide any grounds for justifying a physician's decision to withhold a potentially life saving medical treatment. The physician's merely indirect causal role in passive euthanasia does not relieve him of moral responsibility. A physician who lets a patient die can be morally blameworthy for that action just as much as a physician who deliberately kills a patient.

A third argument that is often heard points out that in medicine one can never be sure of the diagnosis or prognosis for any particular patient. Medicine is not an exact science and physicians are the first to admit that they make mistakes. Every physician as well as every subscriber to *Reader's Digest* can report anecdotes describing cases of patients who miraculously recovered. The argument is then made that the moral difference between active and passive euthanasia is that in active euthanasia such a lucky break (the miraculous recovery) is denied the patient who has been killed by his doctor. The philosopher Tom Beauchamp presents a version of this argument when he points out that if we prohibit active euthanasia we will save those people who are wrongly diagnosed as hopeless, but who would have survived with a good outcome even if treatment had been stopped. (Beauchamp)

I think this alleged moral difference fails both conditions 1 and 2. It fails condition 1 if the significant difference is supposed to be the fact that there will be a greater number of unnecessary or tragic deaths if we permit active euthanasia than if we permit only passive euthanasia. If this is a real difference between active and passive euthanasia, it's also a real difference between passive euthanasia and aggressive treatment. That is, we can make exactly the same kind of comparison between permitting passive euthanasia and prohibiting passive euthanasia. Beauchamp admits that a policy that permits passive euthanasia runs the risk of allowing tragic deaths. If avoiding unnecessary or tragic deaths justifys a policy prohibiting active euthanasia, it would seem on exactly the same score to justify a policy of prohibiting passive euthanasia as well. This alleged difference marks no real difference between active and passive euthanasia.

It also fails condition 2, because even if we assume that the "tragic deaths" are connected only with active euthanasia, this would not be a morally significant difference that would justify prohibiting active euthanasia on request. The patient who is requesting active euthanasia can knowingly accept the risk of false diagnosis and prognosis, which is just what well-informed patients do when they are asked to make any kind of medical treatment or non-treatment decisions.

A third argument that is offered against permitting active euthanasia claims that active euthanasia offers a much greater likelihood of abuse than passive euthanasia, where abuse means killing patients who don't want to die. We can find this argument, for example, in a letter to the *New England Journal of Medicine* from Dr. Fernando Vescia, in response to James Rachel's article: "Central to the condemnation of active euthanasia is the lack of protection from when this choice would be motivated by other than charitable purposes." (Vescia, 1975)

This argument may meet condition number 2, because certainly the likelihood of abuse is a morally relevant consideration in deciding whether or not to permit a certain practice. If indeed active euthanasia offers a much greater likelihood of abuse than passive euthanasia, we would have reason not to allow active euthanasia even on request. At least this would be so if in addition there were no practical mechanisms for reducing the additional threat of abuse that active euthanasia might pose. But even if this argument meets condition 2, it does not meet condition 1, because the potential for abuse does not mark a real difference between active and passive euthanasia.

The worst abuse would be to cause the death of patients whose death was avoidable or forestallable, and who didn't want to die. But one can do this with passive euthanasia as well as with active euthanasia simply by withholding potentially life-prolonging treatments from people who want to continue to live. Indeed, you might argue that abuse of this kind would be easier with passive euthanasia since it would often be plausible in the circumstances to attribute the death to the patient's grave condition, rather than to a physician's decision not to act. I think there is indeed evidence of this kind of abuse of passive euthanasia.

There may, for example, be reason to believe that there is some abuse of passive euthanasia in the institutionalized elderly. In a study appearing in the *New England Journal of Medicine* by Brown and Thompson (1979) it was found that of a hundred and ninety patients in nine nursing homes who had suspected bacterial infections (probably pneumonia, in most cases) antibiotics which probably would have resolved the bacterial infection were withheld from 81 patients. Predictably, of those 81 who were not treated a much larger proportion subsequently died of that infection. In how many of these 81 cases had permission to withhold treatment been granted by the patient and/or the patient's family? Unfortunately Brown and Thompson don't ask the question directly but some of the other information they gather can provide some grounds for making an inference. Usually when permission to withhold a treatment has been explicitly sought by the physician and granted by the patient and/or the patient's family, that permission is noted in the patient's medical records as a very important form of legal protection. Brown & Thompson did determine the cases in which a notation had been made in the patient's medical records of the physician's intention to withhold the antibiotic treatment, which is still not quite the same as a documentation of *consent*. As it turned out in only 23 of the 81 cases was there such a notation. The proportion 23/81 probably represents a liberal estimate of the proportion of cases in which consent had explicitly been granted. That leaves a very large proportion of cases in which abuse of passive euthanasia should at least be strongly suspected.

Despite abuse such as this, the response has not been (and should not be) to call for the prohibition of voluntary passive euthanasia. The more defensible approach is to develop ways to prevent or lessen the abuse. Active euthanasia is just like passive euthanasia in that it, too, poses a threat of abuse. But if the real and present threat of abuse can't justify prohibiting passive euthanasia, then neither can it justify prohibiting active euthanasia.

The final argument that I wish to consider is one that I myself made a couple of years ago but have come to reject (Tomlinson, 1981). The argument points out that permitting voluntary passive euthanasia of competent adults is justified by the existence of a right to refuse treatment which physicians must recognize whether they agree with the decision of the patient or not. There is by contrast no analogous "right to be killed" that would justify active euthanasia because such a "right" would require that physicians actively participate in an action that they may deem immoral. The patient, however, can't have a "right" that the doctor violate his or her conscience. The upshot of the argument is that the moral difference between active and passive euthanasia is that patients have a right to passive euthanasia, which they can demand of physicians, but they don't have any such right to active euthanasia which entitles them to physician cooperation.

Although I once thought that this was a very significant difference between active and passive euthanasia, I no longer believe so. I think that the argument violates both conditions 1 and 2.

First of all I think it fails condition 1 because it does not mark a real difference between active and passive euthanasia. Notice that the argument proposes that the morally relevant distinction between active euthanasia and passive euthanasia is based on the degree of moral responsibility placed upon the physician. When the responsibility is solely the patient's (as in passive euthanasia) it is more defensible to permit it as a matter of policy than when responsibility is "shared" with the physician or thrust upon him (as in active euthanasia). But if this is a genuine distinction that justifies us in accepting one form of euthanasia but in rejecting another it seems to condemn most passive euthanasia as well. The only form of euthanasia that would involve no supporting activity or cooperation from the physician or the hospital is when the patient is permitted to haul himself out of bed and stagger to the elevator under his own power. As a matter of fact, however, we think that patients have a right to something more than this when we advocate a policy permitting passive euthanasia, even though anything more than this is going to require some supporting activity or cooperation from the physician. If the logic of this argument was acceptable, for example, the policy of the University of Southern California Burn Center would have to be rejected. There, burn victims who have burns so severe that their survival is unprecedented are fully counseled on the alternative of no treatment, and if they elect that option they are provided with a private room, unlimited visitation, and full pain relief. (Imbus and Zawacki, 1977)

I also think this argument fails condition 2. Even if there is a real distinction here between active and passive euthanasia so that all and only forms of passive euthanasia are protected by a right that obligates physicians to respect the patient's request, how can that show that only passive euthanasia should be permitted? It shows only that a patient can't justifiably demand that a physician kill him as he can demand to be left alone. But this doesn't show at all what would be objectionable about a *mutually agreed upon* active euthanasia. That is, the argument doesn't show why we shouldn't or couldn't have policies regarding active euthanasia which would be similar to those we now have governing abortions and sterilizations. With abortion and sterilization we can also point out that no patient has a right to demand of a particular physician that he or she perform an abortion or sterilization when that would violate that physician's conscience. But all this point justifies is policies permitting people to refuse to perform abortions or sterilizations. Conscientious refusals cannot justify the prohibition of abortions or sterilizations, any more than they could justify the prohibition against active euthanasia.

These are all the arguments I have space to review. I believe I have successfully shown that each of them fails one or both of the conditions I've set out. If the same is true of any other plausible arguments that might be offered, then I think we will have a well-grounded basis for changing our moral attitude regarding active euthanasia.

Notes

[1] House of Delegates of the American Medical Association, statement issued December 4, 1973.

[2] Rachels, James, "Active and Passive Euthanasia," 1975: *New England Journal of Medicine* 192, pp. 78–80.

[3] Beauchamp, Tom L., "A Reply to Rachels on Active and Passive Euthanasia," 1979: revised for *Medical Responsibility,* Wade L. Robison and Michael S. Pritchard, eds., Humana Press, pp. 181–194.

[4] Vescia, Fernando, correspondence, 1975: *New England Journal of Medicine* 292, p. 865.

[5] Brown, Norman K. and Donovan J. Thompson, "Nontreatment of Fever in Extended Care Facilities," 1979: *New England of Medicine* 300, pp. 1246–1250.

[6] *Public Opinion,* December/January 1983, p. 39.

[7] Ernle W. D. Young, correspondence, 1975: *New England Journal of Medicine* 292, pp. 864–865.

[8] Tomlinson, Tom, "The Moral Difference Between Active and Passive Euthanasia," 1981: Unpublished manuscript.

[9] Imbus, Sharon H. and Bruce E. Zawacki, "Autonomy for Burned Patients When Survival is Unprecedented," 1977: *New England Journal of Medicine* 297, pp. 308–311.

SOME DISTINCTIONS BETWEEN ACTIVE AND PASSIVE EUTHANASIA

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I wish to argue that there is a significant moral difference between passive euthanasia (PE) and active euthanasia (AE). In doing so I will deal in various ways with the issues of intentions, responsibility, uncertainty in prognosis, and the effects of actions on a person's overall character.

Two questions stand out regarding the issue of intentions. Are the intentions in AE and PE the same? And, even if they were the same, or very similar, does that fact make each of the means equal? In other words, does a good intention (wanting to help the patient die a peaceful death) imply that there is no moral difference in the actions used to achieve that goal? Let's look at the second question first. In the Smith-Jones example cited by Professor Tomlinson, "killing" and "letting die" have the same intention, the death of a boy.[1] The analogy is supposed to imply that the intention of a physician (in this case, a morally good one—the peaceful end of suffering) makes "killing" and "letting die" equal as means to achieve the goal. In the Smith-Jones case, it does seem clear that there is no moral difference between killing and letting die. Both Smith and Jones are equally culpable. But I would argue that a physician's situation is different. We can assume the physician wants to be ethical, and moral integrity means *both* means and ends must be examined. In the literature, analogies used to equate AE and PE are almost always blatantly *immoral* acts in which the end makes all means equal. This skews the discussion because if we assume moral integrity to begin with, the end does *not* automatically justify the means. If I want to deceive you, how I do it is simply a matter of how best to achieve my immoral goal. The means is already completely tainted by the end. But if I want to be honest with you, the means I use is *independently* very important because the means itself may have moral dimensions. For example, consider a physician telling a patient he or she is terminally ill. The goal, honesty and respect for a person's right to know, does not mean it is morally all right for the physician to use any means of telling the patient. The means itself could be very harmful and destructive. Compare this with a physician who wants to cover up negligence, and one can see how immorality links means and end as one unit while moral consciousness puts an obligation on the person to view each independently. The example of Smith and Jones killing a child in the bathroom by one of two means sheds very little light on a situation where an individual *with moral integrity* is trying to decide the most moral means to bring about a person's death. Examples of immorality tend to flatten out distinction in means.

What then are some of the differences in the means? The intention of the active euthanizer is expressed by a very clear end-in-view, the death of the individual at a time and place ultimately under the control of the physician. John Dewey pointed out perhaps better than anyone that ends-in-view express the character of the individual as well as form that character in the future.[2] If I choose to steal, I am expressing both the character I have and at the same time forming my character. Part of a reflective moral decision is to consider the effect on one's own moral integrity. There is a very selfish, narrow way of interpreting this—how can I best feel smug about myself or give a good impression? I do not mean that. What I mean is reflection at a very deep level about what kind of *person* you want to become. As Sartre said time and time again, we become our choices. I think one of the things that bothers many physicians about active euthanasia is the potentially formative effect on character and what it will do to their overall view of human life if AE somehow became an accepted, even standard part of their actions. Active euthanasia can be a genuine expression of the need to relieve suffering, but what will it do to the character of an individual whose moral ideal is dedicated to preserving human life if it becomes part of his or her intention to actively take life? What does a physician become when his or her empathy lies in caring for life and he or she becomes an active agent in taking it? Moral conservatism is justified when it comes to killing because of the formative effect of the means on the character of individuals. This is far more than a "public image" problem for the physician. Are they actually going to be morally better people by taking someone's life—regardless of the reason? (Does the social approval of the executioner's action make what he does irrelevant to his moral character?) Because of the effect on the agent of killing another person, our intuitions imply that, even in a tragic situation, such an act must be a last-ditch effort of desperation. My point here is that this intuition is justified.

The effect on an individual can be directly tied to the moral tradition of the West. It is useful here to borrow W. D. Ross's distinction between *prima facie* and actual moral duties.[3] A *prima facie* moral duty is one that, all other things being equal, ought to be followed. For example, all other things being equal, lying is morally wrong and ought not be done. The moral tradition of the West has as one of its basic principles the sanctity and preservation of human life. The *prima facie* rule against taking life ranks higher than probably all other such principles and is countermanded only in certain specified situations such as self-defense. Even in self-defense it is generally agreed that killing the aggressor should be a last resort and that, if killing is not necessary, other forms of self-protection are clearly morally superior. The end, though it may be morally good—protection of self or family—does not make all means equal. In a situation such as physicians face in which the moral agent is forced to choose between actively taking life and letting someone die and these are the only two options to achieve the same goal (a peaceful "good death"), other factors being equal, not doing anything is the morally superior act. There may be times when AE is the only genuine moral alternative. But this does not make killing and letting die morally the same any more than killing someone as a last resort to protect the lives of one's children makes killing as a principle morally equal with other ways of protecting one's family. Where AE and PE are both options, PE recognizes the moral principle of the sanctity of life in the only way available to the person in that situation and, based on that principle, does not actively violate the integrity of the self. Respect for the moral principle of preserving life translates in concrete circumstances into a *prima facie* rule against AE whenever life cannot be maintained and PE is a viable alternative.

The intention of the active euthanizer ties into the causal nature of the act. We normally see the causal feature of moral agency as critical. Degrees of responsibility have always had important ethical implications. Active euthanasia makes the doctor the sufficient condition for the death of the other person. The intention serves to pull together and put under the control of the physician all the conditions necessary for bringing about death. On the other hand, the role of the physician in passive euthanasia is as a necessary condition only. The patient's death requires that the physician not do anything and that act of omission is only one (and frequently it is not even certain it is one) of the necessary conditions. Passive euthanasia puts the physician in the role of being one of a number of necessary conditions for the death of the other; active euthanasia requires the physician to be the sufficient condition.

The difference between being a necessary or a sufficient condition and the link between intention and sufficiency in an act is at the heart of many of the objections to AE. In a situation involving moral uncertainty, active euthanasia usurps all options. Professor Tomlinson's claim that both PE and AE foreclose an indefinite number of options for the patient deliberately blurs the meaning of "indefinite." In AE all options are closed. In PE *almost* all options close for the patient. When one is talking about ending someone's life, that distinction is crucial. Decisions involving PE are frequently clouded by a number of factors. Physicians have told me that in many cases of PE length of life and quality of remaining life are not at all certain. Moreover, cases of people who were "allowed to die" but recovered are known to most physicians and the rare but actual possibility of this occurring makes for an enormous difference in the moral texture of a large number of cases. The lack of infallibility is real for physicians. To be the sufficient condition for the loss of someone's future is more than enough to rule out AE in which possibilities are never even allowed.

Are the intentions in AE & PE really the same? I have implied above that they may not be. I think the strongest case for the difference in intentions has been made by Philippa Foot.[4] Pulling the plug on a respirator will allow a patient to die but if the patient lives we do not sense that we have failed. Because the individual did not die we do not subsequently feel an obligation to kill the person; the original intention was to *allow* to die. On the other hand, the failure of an injection to kill someone is a failure to produce the result directly intended by the agent. Being what it is, the moral intention would oblige us to try again. Foot's point is that having a role in the apparent inevitability of someone else's death varies significantly from directly intended causal agency.[5] Foreseeing death, allowing it to happen, is a fundamentally different intention from being the sufficient condition for death. It is simplistic to equate *in principle* the intentions in active and passive euthanasia and completely unjust to attribute a failure of moral nerve to someone opting for passivity rather than action. Examples such as the Smith-Jones case or those that equate the responsibility involved in negligence to that of PE assume the intentions in AE and PE are the same. My point is that they are not identical and that the difference between them has critical moral connotations. My further point is that, even in cases where the actual intentions are clearly synonymous (and clearly good), that does not make all means morally equal.

Finally, what should be the physician's role if a patient requests active euthanasia? The situation is essentially the same as any other request of a morally complex and difficult act. Since it is a request for a second party to counter a basic moral principle and since the request involves the integrity of the agent's moral self, patients should assume no prior claim on physicians' cooperation. The cooperation of a physician or loved one in helping a person die would depend on the agent evaluating a number of factors, including the request to die as an expression of the patient's autonomy. Autonomy alone may be sufficient for having someone not do anything to your body but autonomy alone is not sufficient to require another person to actively perform an action, especially when the action may countermand a long-standing moral principle. Contrary to Professor Tomlinson, the difference in causal responsibility between AE and PE makes this issue a real one in cases of voluntary euthanasia. Because of this difference and the implications cited earlier in the paper, passive euthanasia is much more easily justifiable by request than active euthanasia. Put another way, in the physician-patient relationship, just as the patient cannot assume on the physician to actively take life, the physician cannot force on the patient full medical treatment against his or her wishes. Both physician and patient have prior claims to say "no" for the same reason—the integrity of the self. In practice passive euthanasia is frequently a compromise between the physician and patient as distinct autonomous agents.

I have tried to show that there are significant moral distinctions to be made between AE & PE and that, if correct, these distinctions are relevant in cases of voluntary requests for AE. While it's possible that AE may be the most necessary and humane act at times (just as lying may be), I think it critical that the moral distinctions be made manifest before any action is taken in a particular situation.

Notes

[1] James Rachels, "Active and Passive Euthanasia," in Thomas Mappes and Jane Zembaty, *Biomedical Ethics* (New York: McGraw-Hill, 1981), pp. 349–50.

[2] See John Dewey, *Theory of the Moral Life* (New York: Irvington Press, 1980), especially chapter 1, sections 4 & 5, and chapter 6.

[3] W. D. Ross, *The Right and the Good* (Oxford: Oxford University Press, 1930), pp. 18–33.

[4] Philippa Foot, "The Problem of Abortion and the Doctrine of Double Effect" and "Euthanasia" in Philippa Foot, *Virtues and Vices* (Berkeley: University of California Press, 1978), pp. 19–32 and 33–61.

[5] See Foot's example of the driver of a runaway tram in "The Problem of Abortion . . . ," pp. 23–24.

FAINT SCREAMS: SWIFT'S "A BEAUTIFUL YOUNG NYMPH" AND THE CRITICS

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The proposal behind this essay is modest enough: I hope to demonstrate, by means of a close look at the strategies of the text itself, that the appropriate affective response to Swift's "A Beautiful Young Nymph Going to Bed" is one of revulsion toward the poem's central character, rather than empathetic and sentimental compassion for her. Of course, this is not to deny the possibility of other readings. Good poetry is sufficiently ambiguous to evoke a variety of significant responses, some of which may have been quite unforeseen by the poet; the text outlives the writer and thereby becomes subject to critical attitudes which may vary widely from those of the age in which it was produced. But my purpose *is* to uncover that reading of the poem which Swift himself most likely intended us to have, so that when we deviate from that reading, we have at least some idea of the primal Swiftian tenets we are manipulating.

"A Beautiful Young Nymph" is commonly linked to three other so-called "excremental" poems—"The Lady's Dressing Room," "Strephon and Chloe," and "Cassinus and Peter"—all produced by the poet during 1730 and 1731.[1] It seems to me that this connection is a tenuous one, although the ways in which the poems are thematically similar do deserve some comment.

Swift's mad persona in *A Tale of a Tub* observes that happiness resides in "a perpetual Possession of being well Deceived." But it is always and everywhere the role of the satirist to force us to look beyond those comfortable constructs by which we seek to delude ourselves into a facile happiness. These four poems are allied in aiming at a stripping away of such obfuscation. They are similar as well as in their overt physicality, in their insistence upon rubbing the reader's nose in the most vile (and fundamental) aspects of the human body, and in their common horror at the rank grossness of human flesh when it is divested of all ornament and is operating in its natural state.

But there are important differences among the poems as well. "The Lady's Dressing Room," "Strephon and Chloe," and "Cassinus and Peter" all have as their "heroes" sentimentally-inclined poetasters who derive ultimately from the romantic Petrarchan tradition. They are characters who so deceive themselves about the supposedly angelic natures of their lovers that they leave themselves open to being psychologically shattered by the contravening evidence of the ladies' stark physicality. Excrement in these poems serves the purpose of what we might call rhetorical gravitation. By means of substituting parodic images of physicality and elimination for the anticipated romantic description, Swift undercuts these swains' delusive notions—notions which were supported by the sentimental literary conventions of the day. Women here are not so much castigated for defecating, as are their lovers for supposing them incapable of it.

Excrement in these three poems therefore helps to fulfill the traditional corrective aims of satire. When, at the close of "The Lady's Dressing Room," we see Strephon "blind/ To all the charms of Female kind" (11. 129-30), we understand that he is a satiric victim who parallels the condition of Lemuel Gulliver at the end of his *Travels.* Both characters are ridiculed for having posited a vision of mankind which is finally suprahuman and which belies the essential nature of the race. A recent article tries to deny this thematic kinship between Strephon and Gulliver by arguing that "Gulliver entertains no illusions about the beastly Yahoos while Strephon has been misled by romantic love."[2] But this misses the point entirely. Just as the discovery of Celia's excremental aspects leads to Strephon's misogyny, so Gulliver's discovery of his own kinship with the Yahoos—most clearly expressed in the swimming hole incident of Book IV—leads to an unreasonable misanthropy. Gulliver's world-view is so blighted by this stripping away of illusion that he is blind to the merits of a thoroughly good man, Don Pedro; similarly, Strephon can finally approach even the most beautiful women only by stopping his nose. Denied the numbing lies of romantic idealism, Strephon takes to woman-hating with the alacrity that Gulliver takes to the stables.

The movement from the romantic to the satiric world-vision, therefore, is seen to be fraught with danger. As Nora Crow Jaffe notes, the satiric writer "makes a bargain with the devil" when he seeks to blast comfortable illusions and uncover the damnable facts;[3] an eye, once jaundiced, may come to view everything as being irreversibly tainted, as Swift himself warns in "Strephon and Chloe":

> But, e'er you sell yourself to laughter,
> Consider well what may come after,
> For fine ideas vanish fast,
> While all the gross and filthy last. (11. 231-4)

Therefore the satirist buys the accuracy of his vision at a frightful price; for that reason, perhaps, he intends to rock the complacent and to disrupt the *status quo* by hitting at us precisely where we are most vulnerable and most repressed. Where is that? "The history of Swiftian criticism," replies Norman O. Brown, ". . . shows that repression weighs more heavily on anality than on genitality."[4] The violence of the reaction prompted by these poems only substantiates their point of view; when we lose our critical perspective and attack Swift for informing us of Celia's defecation, we merely recapitulate the error of Strephon and reveal the depths of our own illusions.

"A Beautiful Young Nymph," then, shares with these other poems the informing theme of sham *versus* reality and romantic delusion *versus* satiric accuracy. But there the similarities end. The poem, while grossly physical, contains no mention of excrement *per se* (save that of a cat). Nor is the poem much concerned with deriding or parodying romantic literary conventions, although the title and Corinna's name do make allusions in that direction, and a parodic similarity between this poem and Donne's elegy, "To His Mistris Going to Bed," has been argued by several scholars.[5]

Unlike "Strephon and Chloe," for example, "A Beautiful Young Nymph" depends very little on its narrative content. Rather, what we get is a sort of Hogarthian engraving—or a series of them—which portrays a Drury Lane prostitute in the privacy of her bedchamber. Swift etches three separate portraits: the lady's preparations for bed (11. 1-38), her fitful dreams (39-59), and her waking to disaster (58-64). The "I" of a persona—Swift himself?—then intrudes (65-74) to provide a sort of moral coda (to mix the metaphor) to the whole composition.

The long passage which relates Corinna's getting ready for bed has elicited some predictible squeals from what Jaffe calls the "shocked school of criticism." John Middletown Murry, for example, refers to the "horror" and "nausea evoked by the hideous detail" of the passage, and he chides Swift for his "total lack of charity, his cold brutality, towards the wretched woman who is anatomized. . . . It is utterly inhuman."[6]

Perhaps. But what happens in this section of the poem must strike the general reader, unless he is either saint (and therefore in no need of Swift's corrective satire) or prude (and therefore beyond its help), as being genuinely hilarious. The prostitute's ills are so calamitous and her prosthetic efforts after beauty are so patently absurd that she calls forth much more laughter than empathy; and this is as it should be. While any of us might respond with the milk of human kindness toward a "beautiful nymph" with, say, a glass eye, that milk becomes distinctly clabbered when we learn that the same woman is bald, has eyebrows made from the skin of mice, has no teeth, props up her breasts with rags, and wears a steel-ribbed corset and artificial hips. The whole sketch is so purposefully and grotesquely overdone as effectively to block any empathetic response on our part. For Corinna is not *real:* she is neither drawn realistically nor is her body so much flesh and blood as it is steel, ivory, glass and wire. Real people may be tragic; Corinna, a character out of a bizarre Saturday matinee cartoon or a slapstick farce, can never be either real *or* tragic. And when Murry refers to this preposterous stick figure, this uproarious demi-machine, as a "wretched woman"—that is, as if she were someone we might actually *know*—we find ourselves laughing at him, too.[7]

The second section of the poem does provide some problems, and one assumes that it is this passage which especially prompts protective urges within the manly breasts of certain critics. Corinna is now in bed, and she

> With Pains of love tormented lies;
> Or if she chance to close her Eyes,
> Of Bridewell and the Compter dreams
> And feels the lash, and faintly screams. (39-42)

But it is likely that Corinna's "pains of love" are less the pangs of unrequited passion than the surely-requited symptoms of venereal disease, one of her many occupational hazards. Further, if she screams "faintly," it is because she is, after all, asleep; the adverb should not provoke us into unwarranted pathos. It has been noted that dreams, in Swift, are consistently in accord with the character of the dreamer, so that the lurid nature of Corinna's phantasms only underscores her own moral wretchedness.[8] Her slumber does call up scenes of deportation, abandonment, and constables, but she also

> . . . seems to watch on lye
> And snap some Cully passing by. (49-50)

The imagery of this couplet is decidedly predatory, and we should recall that even gentle Gay, Swift's friend, used a similar trope in his *Trivia* to warn against contact with the ladies of Drury Lane:[9]

> She leads the willing victime to his doom,
> Through winding alleys to her cobweb room.
> (*Trivia,* 3, 11. 291-2)

The most palpable result of such contact is, of course, the "pox" with its "cancers, issues, [and] running sores"—symptoms which Corinna herself helps to disseminate. Further, we learn at the end of this part of Swift's poem that she numbers among her clients those clergymen

> Whose favor she is sure to find,
> Because she pays 'em all in kind. (55-6)

So Corinna actively corrupts the representatives of established religion. To be sure, she is as much sinned against as sinning in these unholy relationships, and Swift's principal satiric target here is probably the clergy, not the bawd. It is clear, however, that the intimacy is corrosive on both sides. Downtrodden and oppressed in most aspects of her life, Corinna nonetheless has the power to contribute to the undoing of the priests of God's Church. Therefore she must not be viewed sympathetically: as Swift emphasizes at the poem's end, Corinna represents an outright social menace.

Lest we be lulled into empathy by social or moral ambiguity, Swift abruptly returns us in the poem's third section to the disjointed world of Max Sennett farce. Corinna wakens to find her glass eye stolen by a rat, her wig infested with her dog's fleas, and her "plumpers" soiled by her incontinent cat. The reader needs only to visualize this scene to capture its overt hilarity. Further, the insistent animal imagery of the passage should serve to warn us against taking Corinna's "mangled plight" too much to heart.

The fourth and final section at last introduces the narrator, the "I" who presumably has told the story thus far. He is at the point of giving up the task:

> But how shall I describe her Arts
> To Recollect the scattered Parts?
> Or show the Anguish, Toil, and Pain. . . .

Like Humpty-Dumpty, Corinna here becomes a literal embodiment of the fragmented personality: her "self" is veritably strewn all over the floor, appropriately soiled by rats, fleas, and animal excrement. The "anguish, toil and pain" she must undergo to restore her mechanical, factitious body is, we must remember, effort aimed at moral and physical corruption:[10]

> Corinna in the morning dizen'd
> Who sees, will spew; who smells, be poison'd.
> (73-4)

This closing couplet recalls that other Corinna—Pope's in the *Dunciad*—who "chanced that morn to make" the puddle of urine in which Curll falls. (In fact the name Corinna was used by Dryden, Pope and Swift to refer variously to Mrs. Manley, Mrs. Eliza Haywood, Mrs. Elizabeth Thomas and Martha Fowke; in all cases the name is attached to a woman who is subjected to savage Juvenalian satire.)[11] Further, the couplet re-emphasizes the point that Corinna is a sort of walking contagion at loose in the city. Whoever approaches her is indelibly blighted. Pope's Sappho at least offers one an alternative between libel and infection; Swift's Corinna imparts only the latter.

In summary, Swift in this poem presents us with what Maurice Johnson has called a picture of "the wages of sin . . . [like] a preacher shouting hell-fire and brimestone, or the photographs in a medical treastise."[12] There is little in what we know of Swift the man or Swift the satirist to persuade us that this poem is other than the "pure invective against vice" that Jaffe takes it to be.[13] I have sought to demonstrate that neither does the poem itself, as an artistic entity, contain evidence to convince us that Corinna is any more like Moll Flanders than Swift's sensibilities are like Defoe's.

Notes

[1] This grouping is found in Jaffe (see citations below), who adds "The Progress of Beauty" to the list. Brown includes only three of these poems under the "excremental" heading: "The Lady's Dressing Room," "Strephon and Chloe," and "Cassinus and Peter." Johnson groups the poems similarly. Murry conforms to Jaffe, but omits "The Progress of Beauty" from his discussion.

[2] Rev. of "Swift's 'The Lady's Dressing Room,'" by Douglas Calhoun, *Scriblerian,* 3.2 (Spring 1970), 56.

[3] Nora Crow Jaffe, *The Poet Swift* (Hanover, NH: Univ. Presses of New England, 1977), p. 112.

[4] Norman O. Brown, *Life Against Death* (Middletown, Conn.: Wesleyan Univ. Press, 1959), p. 180.

[5] For example, see Irwin Ehrenpreis, *The Personality of Jonathan Swift* (London: Methuen, 1958), p. 42; and Robert Hunting, *Jonathan Swift* (New York: Twayne, 1967), p. 48.

[6] John Middleton Murry, *Jonathan Swift* (London: Jonathan Cape, 1954), p. 439. See Ehrenpreis, p. 33. (Lady Pilkington reportedly vomited upon reading the poem and saw it as "all the dirty ideas in the world in one piece"; see Ehrenpreis, p. 37, and Hunting, p. 74.)

[7] "Corinna," writes Denis Donoghue, "is a machine, her bedroom a factory; when she goes to bed, the factory is shut down"; see Donoghue's *Jonathan Swift: A Critical Introduction* (Cambridge: Cambridge Univ. Press, 1969), p. 207. As Ehrenpreis (p. 46) notes, the depiction of such mechanical women is a "staple motif in American humorous literature." Hunting (p. 48) objects that the whore is "not funny" and is "horrible to contemplate"; he accuses (p. 77) Swift of exaggeration: "Surely no such 'heroine' as Corinna ever lived." This, of course, is exactly my point in the present study.

[8] Donoghue, p. 199.

[9] It seems likely to me that Swift, in his couplet, makes a scriptural allusion: *cf.* Proverbs 7.

[10] Donoghue (p. 207) rightly refers to Corinna, in her efforts to reassemble her personhood, as "a resourceful mechanic."

[11] Marcia Heinemann, "Swift's 'Corinna' Again," *Notes and Queries,* 19 (June 1972), 218-21.

[12] Maurice Johnson, *The Sin of Wit* (Syracuse: Syracuse Univ. Press, 1950), p. 115.

[13] Jaffe, p. 105.

EMOTION AND PHILOSOPHY OF MIND: D. H. LAWRENCE'S NARRATIVE TECHNIQUE

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D. H. Lawrence reveals emotion through at least six narrative methods, three drawn from Philosophy of Mind and three transcending it. Considerations drawn from Philosophy of Mind provide titles for three of Lawrence's methods: (1) descriptions of bodily feeling; (2) descriptions of behavior which directly reveals emotion; (3) descriptions of states of consciousness. In addition, Lawrence relies upon three "literary" narrative techniques which transcend those identified through Philosophy of Mind; the literary methods for revealing emotion are: (4) the loading of a scene with overtones of emotion felt but not recognized by the characters; (5) descriptions of external objects and other people which actually reveal emotion in character; (6) symbolic action—behavior of characters which reveals emotion indirectly by reference to a system of ideas established elsewhere in the work.

Controversies in Philosophy of Mind provide the context for these categories. Philosophy of Mind contains the study of emotions; and in this pursuit, Jean-Paul Sartre identifies three categories that we can apply to Lawrence: bodily reaction, behavior, and states of consciousness. Philosophers of Mind split into two groups depending on whether they consider these categories as sources for facts or as directly intuited phenomena. Philosophers seeking to study emotion through isolating facts as in any other scientific investigation fall into the psychological school of Philosophy of Mind; those seeing emotions as self-significant phenomena fall into the category of the Phenomenologists. In seeking to establish relationships among the three basic categories, the psychological school splits: theorists of the intellectualist persuasion hold that there is "a constant and irreversible succession between the inner state considered as antecedent and the physiological disturbance considered as consequents."[1] In contrast, the second psychological theory, called the peripheric theory, which holds that "a mother is sad because she weeps," reverses the order of the factors, claiming that bodily disturbances cause the mental states which we recognize as emotions. The reliance of both branches of the psychological school upon facts, which have no significance in themselves, says Sartre, led to the reaction known as Phenomenology. Its founder Hussrl (and also Heidegger and Kierkegaard) directed attention toward emotion as phenomena the significance of which can be directly and intuitively known.

In arguing against the position of the Phenomenologists, Moreland Perkins relates the theme to literature and specifically to Lawrence's narrative techniques. Perkins's argument appears in an article in *The Philosophical Review* (1966); while not holding with William James the extreme peripheric position that emotion is *merely* our awareness of bodily feeling, Perkins does argue that "bodily feeling occupies a central place in emotional experience."[2] To support his claim, Perkins contends that novelists who are noted for "their power to convey to us the emotions felt by their 'characters,' " gain their power by including mention of the characters' bodily feelings. Perkins's first example comes from Lawrence's *The Rainbow* in the scene where Tom Brangwen proposes to Lydia Lensky: "She quivered, feeling herself created, will-less, lapsing into him, into a common will with him.''[3] Perkins points out that the sentence is about emotion although there is no emotion word in it or near it in the text. ''The emotion has no common name and it needs none,'' says Perkins (p. 156). In Sartre's terminology, ''quivered'' refers to a bodily reaction while ''feeling herself lapse . . .'' indicates a state of consciousness. However, according to Perkins, ''the participle 'feeling' modifies the verb 'quivered,' follows fast upon 'quivered,' and depends upon 'quivered.' '' Perkins says that the word ''quivered'' is needed to ''convince the reader that at this very moment this woman *felt* what the rest of the sentence explains'' (p. 157). On such examples rests Perkins's argument that emotion is best conveyed through bodily feeling.

However, a wider examination of Lawrence's technique for revealing emotion indicates that Perkins overemphasizes bodily feeling as Lawrence's narrative technique. For example, in the opening pages of *Women in Love* we see elements of exterior behavior used alone and in combination with states of consciousness. In such combinations they form an exterior/interior counterpoint that multiplies, rather than merely adds their effects. In the novel's opening scene, two sisters, Ursula and Gudrun, discuss marriage, especially the unhappy situation by which a woman must marry in order to be ''in a better position.''[4] Gudrun, who is sketching, picked up her eraser ''almost angrily,'' according to the author. Here, Lawrence puts the reader into the position of someone in the room, observing the conversation; he implies that we at times detect emotions by observing simple bodily gestures such as Ursula's picking up the eraser. This assumption, underlying the narrative technique, continues as Lawrence says that ''Gudrun flushed dark.'' Here we are to draw whatever conclusions about her emotions that we might draw if we were present in the room and saw her blush. In these examples Lawrence primarily relies on describing behavior which is assumed to directly reveal emotion. However, Lawrence does not limit himself to external signs. When Ursula says that she has turned down a marriage offer that would have meant ''a thousand a year, and an awfully nice man,'' she says she was not tempted; ''I'm only tempted *not* to,'' she says, and we then find the following sequence:

> The faces of both sisters suddenly lit up with amusement. ''Isn't it an amazing thing,'' cried Gudrun, ''how strong the temptation is, not to!'' They both laughed, looking at each other. In their hearts they were frightened. (*Women in Love,* p. 2)

Lawrence describes emotion through behavior in the passage: the faces ''lit up'' and the sisters laughed. As a person present in the room, one could only assume that the women felt delight and amusement. But in the last sentence Lawrence introduces the counterpoint, claiming that both also felt fear, and Lawrence uses what Sartre called state-of-consciousness terminology to introduce this contrasting, tension-producing fact of secret fear. Bodily feeling, which Perkins stresses, is absent, yet the passage gains strength through the tension between outward amusement and inward fear.

An amplifying example comes later in the novel. In describing the complex relationship between Gerald Crich and Rupert Birkin in *Women in Love,* Lawrence resorts to externals of behavior and to bodily feeling in the well-known ''Gladiatorial'' chapter in which the two men strip and wrestle ''swiftly, rapturously, intent and mindless at last, two essential white figures working into a tighter, closer oneness of struggle'' (*Women in Love,* p. 263). But Lawrence has no reservation about also having his character Birkin later explain in state-of-consciousness terminology that ''to make it complete, really happy, I wanted eternal union with a man too: another kind of love'' (*Women in Love,* pp. 472–73). In such subtle interaction of behavior and state-of-consciousness, Lawrence's narrative technique serves him well. Birkin's expression, "another kind of love," would communicate little if Lawrence had not preceded it with active depictions of both behavior and bodily feeling which give flesh to the skeleton provided by the concept word, "love."

Perkins's contention is that Lawrence relies on bodily feeling because this narrative technique is intrinsically the best way to present emotion. This is not the case; complex literary considerations dictate Lawrence's choice. Furthermore, Lawrence could not rely exclusively on state-of-consciousness techniques for narrative presentation of emotion because one of Lawrence's central situations is that in which the character denies or refuses to become conscious of an emotion. In his story, "The Prussian Officer," for example, Lawrence describes an officer's "passion" for his enlisted man. The officer, according to Lawrence, "was a gentleman, with long, fine hands and cultivated movements, and was not going to allow such a thing as the stirring of his innate self. He was a man of passionate temper, who had always kept himself suppressed."[5] Although Lawrence does not specify the emotion as homosexual passion, he does stress the officer's barren emotional sex life with women and his bachelorhood at age forty. "He *would* not know that his feeling for his orderly was anything but that of a man incensed by his stupid, and perverse servant," says Lawrence. "So, keeping quite justified and conventional in his consciousness, he let the other thing run on" (p. 100, my emphasis).

Lawrence readily uses state-of-consciousness words such as "anger" and "hate" in this story. But, writing in the early twentieth century, Lawrence may have been reticent to openly broach the topic of homosexuality; thus, in addition to the problem of depicting an emotion being internally censored by the character, Lawrence was himself contending with external forces of censorship. In such a situation, Lawrence turns to Sartre's first category, bodily sensation, to reveal emotion. The young soldier's presence "was like a warm flame upon the older man's tense, rigid body," (p. 97) and later: "The officer's heart was plunging" (p. 101). The situation is even more subtle than we have so far explained. It is not that the captain felt homosexual desire and covered it with feigned anger, but that, in blocking himself from awareness of the nature of his passion, the officer really did feel anger instead. Furthermore, the officer's primary defense against recognizing his emotion has apparently been to withdraw from the animal instincts, to become abstract and intellectual. And it is with state-of-consciousness "emotion words" like "hate" that Lawrence reveals how the soldier's presence unintentionally weakened the captain's defense: "To see the soldier's young, brown, shapely peasant's hand grasp the loaf or the wine bottle sent a flash of hate or of anger through the elder man's blood (p. 97). Later in the story it is the youth's unconscious animality in putting that same arm around the soldier's girlfriend that incenses the officer. That Lawrence describes the young soldier's reciprocal hatred and anger in terms of intense bodily feeling may be because Lawrence has introduced the youth as a person who "seemed never to have thought, only to have received life direct through his senses, and acted straight from instinct" (p. 97). The use of bodily feeling is thus not dictated by the absolute notion that this is the "best" way of depicting emotion as Perkins suggests, but by the requirements of a complex narrative situation.

Lawrence resorts to a more purely literary technique in solving a similar problem when he describes the beginning of sexual attraction between Paul and Miriam in *Sons and Lovers*. The education of both children has been so restrictive that neither would recognize a sexual feeling in him or herself. Therefore neither could think of the emotion in what Sartre called state-of-consciousness terminology. One solution to this problem is revealed by a study of the swing scene in the chapter entitled "Lad and Girl Love" in *Sons and Lovers*. The external behavior is nothing beyond an innocent exchange of swinging on a rope and pushing each other; there is no state-of-consciousness language in either Lawrence's words or the characters' minds to indicate sexuality; and, although the bodily-feeling language is much more intense than one would expect for a mere swing ride, this language standing alone does not necessarily indicate sexual emotion. Lawrence, therefore, resorts to having the conversation and description carry overtones of sexuality that are unintended by the characters though almost certainly intended by Lawrence. Consider the following sequence:

> . . . the youth and girl went forward for the great thick rope . . . then immediately he rose . . . she made the swing comfortable for him. That gave her pleasure. . . . Almost for the first time in her life she had the pleasure of giving up to a man . . . in a moment [he] was flying . . . she could feel him falling and lifting through the air . . . "Now I'll die," he said, in a detached, dreamy voice . . .[6]

The youth and girl are completely unprepared to think in concepts about sexual emotions and know only that they are feeling something.

Lawrence's narrative method of loading the scene with sexual overtones becomes even more evident when Miriam takes her turn:

> "It's so ripping!" he said, setting her in motion. "Keep your heels up, or they'll bang the manger wall."
>
> She felt the accuracy with which he caught her, exactly at the right moment, and the exactly proportionate strength of his thrust, and she was afraid. Down to her bowels went the hot wave of fear. She was in his hands. Again, firm and inevitable came the thrust at the right moment. She gripped the rope, almost swooning. (*Sons and Lovers,* p. 151)

When Paul "mounted again," the sexual parallel continues although this time from the perspective of Miriam as she watches Paul:

> Away he went. There was something fascinating to her in him. For a moment he was nothing but a piece of swinging stuff; not a particle of him that did not swing. She could never lose herself so, nor could her brothers. It roused a warmth in her. It were almost as if he were a flame that had lit a warmth in her whilst he swung in middle air. (*Sons and Lovers,* p. 151)

In the swing scene Lawrence avoids state-of-consciousness language where sexuality is concerned but does not hesitate to name states-of-consciousness when speaking of fear or fascination. There is also no overtly sexual behavior, yet sexual attraction in an innocent "Lad-and-Girl Love" is surely the topic. Bodily feeling depicted by the "hot wave" and "flame" images, though excessive for a mere swing ride, would not be enough in themselves to communicate sexual attraction, so Lawrence sprinkles the passage with words and phrases that would be appropriate for the description of adults making love: "pleasure . . . giving up to a man . . . flying . . . falling and lifting . . . 'Now I'll die' . . . 'Keep your heels up' . . . firm and inevitable came his thrust . . . mounted again . . . he was nothing but a piece of swinging stuff." Thus we see, not a Lawrence favoring bodily feeling over the other two categories, but an author choosing his narrative strategies among the three Philosophy of Mind alternatives, combining them in various ways according to the situation and adding purely literary techniques that go beyond Sartre's three categories.

The relationship between Gertrude and Walter Morel in *Sons and Lovers* is another such complex interaction of emotions where Lawrence uses a purely literary technique—the description of an external object to reveal emotion. Lawrence certainly does not shrink from depicting emotion through bodily feeling in this book; after one argument, the pregnant Gertrude Morel "walked down the garden path, trembling in every limb, while the child boiled within her" (*Sons and Lovers,* p. 23); however, in this novel we also see Lawrence using external objects to correlate with internal emotion. At the very moment Gertrude is having the baby, Walter works in the mine on a rock "that was in the way of the next day's work. As he sat on his heels, or kneeled, giving hard blows with his pick, 'Uszza—uszza!' he went," says Lawrence. Walter's workmate advises him to avoid "hackin' thy guts out," but Morel insists on overworking himself into a frenzy (*Sons and Lovers,* pp. 30–31). He is the last to quit the mine and when he arrives home he finds to his surprise that Gertrude has given birth to his son, Paul. Lawrence does not comment on the physical parallel between the birth struggle and the effort to dislodge the rock from the coal seam, but the parallel works subtly to inform the reader that both of these people are besieged by frustrating emotional conflicts.

A similar, but even more revealing use of an external object occurs in *Women in Love* as Ursula walks through the woods:

> She started, noticing something on her right hand, between the tree-trunks. It was like a great presence, watching her, dodging her. She started violently. It was only the moon, risen through the thin trees. But it seemed so mysterious, with its white and deathly smile. And there was no avoiding it. Night or day, one could not escape the sinister face, triumphant and radiant like this moon, with high smile. (*Women in Love,* p. 237)

While Lawrence ostensibly describes the moon as an external object, he is really opening the reader to depths of Ursula's emotion. In Ursula's violent start, Lawrence does give us a behavioral component of her emotion but this would be far less meaningful if it were not combined with attributing to the moon a deathly smile, a sinister and triumphant face, and a desire to watch Ursula. These are obviously not realistic attributes of the moon but projections of the woman's emotion.

A similar concept of projection helps provide the rationale for explaining several profoundly emotional scenes in *The Rainbow.* Two kissing scenes—involving Anna Brangwen and, after the span of a generation, her daughter Ursula—reveal the subtle effect of projection when the projection is applied not to an object but to another person. Lawrence narrates both scenes in third person from the point of view of the male partner of the encounter. In the first, Lawrence employs bodily feeling to reveal the young man's emotion; the scene thus parallels the one explicated by Professor Perkins. The second contains projection in contrast to the earlier scene between Tom and Anna Brangwen. In the scene with Anna and Tom:

> "My love," she said, her voice growing rapturous. And they kissed on the mouth, in rapture and surprise, long, real kisses. The kiss lasted, there among the moonlight. He kissed her again, and she kissed him. And again they were kissing together. Till something happened in him, he was strange. He wanted her. He wanted her exceedingly. She was something now. They stood there folded, suspended in the night. And his whole being quivered with surprise, as from a blow. He wanted her, and he wanted to tell her so. But the shock was too great to him. He had never realized before. He trembled with irritation and unusedness, he did not know what to do. (*The Rainbow,* p. 120)

The passage continues mostly with repetition for effect and with Lawrence's depiction of Tom's gradual return to awareness of their surroundings in a moonlit field. Although the opening sentences could be interpreted as a neutral third-person narrative from outside the actors, the latter part makes clear that Lawrence is telling us what Tom feels, the words "quivered" and "trembled" providing a component of bodily feeling.

The following similar passage contains a decisive difference; here Lawrence describes the kiss of Anton and Ursula, Anna's daughter:

> Then there in the great flare of light, she clinched hold of him hard, as if suddenly she had the strength of destruction, she fastened her arms round him and tightened him in her . . . increasing kiss, till his body was powerless in her grip, his heart melted in fear from the fierce, beaked, harpy's kiss. The water washed again over their feet, but she took no notice. She seemed unaware, she seemed to be pressing in her beaked mouth till she had the heart of him. (*The Rainbow*, p. 479)

This passage expresses Anton's fear of Ursula's passion. Using a state-of-consciousness term, Lawrence clearly states that the man was in "fear." This fear becomes evident to the reader, however, more through attributes ostensibly attributed to Ursula: her "strength of destruction," for example, and her harpy's beak. Like the grinning moon of the earlier quoted passage, these supposed attributes of Ursula tell us more of Anton's emotion than they do about Ursula. Anton may notice the lapping of the wave about their feet but she "seemed unaware," terminology which indicates that Lawrence is narrating the passage from outside of her mind. And, since they are not realistic descriptions, the best assumption is that such depictions reveal the emotion that Anton felt toward Ursula.

After this kiss, Ursula initiates a sexual encounter with Anton Skrebensky, and then she breaks off with him, finding the experience utterly unfulfilling. Subsequently discovering herself with child, Ursula thinks she might write to Skrebensky in India where he has been posted and, unbeknownst to her, been married to his colonel's daughter. Ursula tries to convince herself that "Only the living from day to day mattered," that she "had been wrong, she had been arrogant and wicked, wanting that other thing, that fantastic freedom, that illusory, conceited fulfillment which she had imagined she could not have with Skrebensky" (*The Rainbow*, pp. 483–84). She asks whether it is not enough that she be satisfied with "her man, her children, her place of shelter under the sun" (*The Rainbow*, p. 484). Ursula has tried through her part of the novel to break the bounds of such conventionality, and been thwarted at every turn; she now considers giving in to the pressure to be a conventional wife: "Was it not enough for her, as it had been enough for her mother?" she asks (p. 484). This would run totally contrary to Ursula's emotional needs. Lawrence has thus set himself the task of revealing the emotion of a character who is, herself, denying those emotions.

Behavior and state-of-consciousness are inappropriate narrative methods for this situation; and, since the character is steadfastly deceiving herself about her bodily feelings there is little chance that the reader will correctly understand the emotional implications of Ursula's bodily feeling.

To solve this problem Lawrence again goes beyond the three basic tactics laid down by Sartre and employs a literary tactic unrelated to Philosophy of Mind: symbolic action. In a depressed state, Ursula wanders into a field. It is raining, and thunder and lightning begin. Suddenly she hears horses' hoofs beating on the path ahead of her; she turns but the riderless horses head her off. Each way she turns they are waiting for her, blocking her back. The horses roar very close, terrorizing her; "in a flame of agony, she darted, seized the rugged knots of the oak tree and began to climb" (*The Rainbow*, p. 489). We do not need to evoke Lawrence's frequent use of trees as male sex symbols to see the episode as a microcosmic recapitulation of Ursula's emotional development in the novel; both in the scene and in the novel at large she has made determined efforts and been brought to bay. But she uses the branches of the oak to reach the hedge and to fall in a heap on the other side. The horses were stopped by the hedge: "They were almost pathetic now. Her will alone carried her" across the bare field, "till, trembling, she climbed the fence" (*The Rainbow,* p. 489).

After this experience, Ursula "was very ill for a fortnight" (*The Rainbow,* p. 490). She experiences the illness as a compression, finally realizing that the "compression was Anton and Anton's world . . . She fought and fought and fought all through her illness to be free of him and his world" and at last succeeded (p. 491). Thus Lawrence continues the parallel, and the episode in the field with the horses serves not only to recapitulate but to forecast Ursula's assertion of her will over the forces that are trying to block her into a conventional existence. Not only does the scene reveal Ursula's emotion subtly and intensely, it also serves, along with the ensuing illness, as the catalyst for her decision not to marry Anton. The child is lost through miscarriage but she knows "it would have made little difference" to her decision (p. 493). Anton's telegram revealing the fact that he is married comes only as a relief to Ursula.

Symbolic action forms a literary strategy in the "Moony" chapter of *Women in Love,* where Ursula watches from hiding as Birkin moves near the mill pond. She first hears him address the Near-Eastern moon goddess: "Cybele—curse her!" He thus evokes an entire mythology of the Virgin goddess of the moon, as well as centuries of associated commentary and philosophy. Birkin then collects rocks and begins stoning the image of the moon in the mill pond. When Birkin finally relents from his temporary state that Lawrence says is like "a madness," Ursula reveals herself from her hiding place and asks Birkin, "Why should you hate the moon? It hasn't done you any harm, has it" (*Women in Love,* pp. 238–241). But Birkin answers with his own question, "Was it hate?" Neither can answer and they lapse into silence. The mythological allusion and Birkin's symbolic action evoke in the reader a complex reaction to an extremely intricate set of emotions. Birkin's question points out that our existing "emotion" terminology is inadequate to handle such a situation through abstract concepts.

Moreland Perkins's thesis that Lawrence derives his power in communicating emotion primarily from his use of the bodily-feeling component of the emotion is thus not an accurate description of Lawrence's practice. As we have seen in this paper, Lawrence uses the bodily-feeling component when that is the most appropriate, but he also uses the other two categories laid out by Sartre—state-of-consciousness and behavior—when they are most appropriate. Lawrence not only uses these three categories in various combinations, but he also goes beyond the categories taken from Philosophy of Mind to create more purely literary methods of narration, such as loading a scene with overtones, the description of objects and even of other characters to reveal emotion, and the working out of elaborate symbolic actions such as the horses in *The Rainbow* and the stoning of the moon in *Women in Love.*

A scene from *Sons and Lovers* perhaps provides an insight into Lawrence's operating principle. Miriam looks at one of Paul's paintings and asks, "Why do I like this so?" Paul answers:

> It's because—it's because there is scarcely any shadow in it; it's more shimmery, as if I'd painted the shimmering protoplasm in the leaves and everywhere, and not the stiffness of the shape. That seems dead to me. Only this shimmeriness is the real living. The shape is a dead crust. The shimmer is inside really. (*Sons and Lovers,* p. 152)

These are the relatively inarticulate words of the young Paul Morel, but if expanded they could perhaps be considered somewhat of a creed for Lawrence in his narrative method. Human emotion, revealed and projected outward, stands at the center, at times giving meaning, "shimmeriness," to the landscape, the rocks in Walter Morel's mine, and the remote moon.

Notes

[1] Jean-Paul Sartre, *The Emotions: Outline of a Theory,* tr. Bernard Fechtman (New York: Philosophical Library, 1948), p. 7–8.

[2] Moreland Perkins, "Emotion and Feeling," *The Philosophical Review,* 75, 2 (April 1966), p. 155.

[3] D. H. Lawrence, *The Rainbow* (1915; rpt. New York: Viking, 1961), p. 40. Further references to *The Rainbow* are to this text.

[4] D. H. Lawrence, *Women in Love* (1920; rpt. New York: Viking, 1960), p. 1. Further references to *Women in Love* are to this text.

[5] D. H. Lawrence, "The Prussian Officer," *The Complete Short Stories of D. H. Lawrence,* Vol. 1 (New York: Viking, 1961), p. 98. Further references to "The Prussian Officer" are to this text.

[6] D. H. Lawrence, *Sons and Lovers* (1913; rpt. New York: Viking, 1968), p. 150. Further references to *Sons and Lovers* are to this text.

SAMUEL MILLER: A TARGET FOR WASHINGTON IRVING

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Knickerbocker's History of New York (1809), Washington Irving's first book, secured fame for its twenty-six-year-old author and created the enduring persona of Diedrich Knickerbocker, whose account of the Dutch settlement has remained vivid while the works of more sober historians fade. Though critics have counted the *History* among Irving's most effective creations, even firm admirers have been impatient with its Book One; written in collaboration with Washington's brother Peter, it recounts competing theories of creation while tracing New York's history back to the origins of the world. Richard Henry Dana, for example, thought it "laborious and up hill,"[1] and Edwin W. Bowen described the first chapters as "somewhat stilted, pompous and pedantic," and felt that they made "the unhappy impression that the authors were feeling their way and were not yet sure of their footing."[2] This view is lent support by literary historians' failure to find clear targets for the satire of Book One; for the vigor of the *History*, as Henry S. Canby remarked, depends upon Irving's "own observation, his own prejudice and rooted dislike, to add to the documents he drew upon."[3]

How the learned affectation of Book One might reflect anything more than some general Swiftian pretensions at first seems baffling. The 1809 edition announced that Book One was, "like all introductions to American histories, very learned, sagacious, and nothing at all to the purpose."[4] All American histories are rather an amorphous target, though in his 1848 "Author's Apology," Washington suggests a slightly narrower aim:

> "To Burlesque the pedantic lore displayed in certain American works, our historical sketch was to commence with the creation of the world; and we laid all kinds of works under contribution for trite citations, relevant or irrelevant, to give it the proper air of learned research."[5]

However, Irving editors Stanley T. Williams and Tremaine McDowell were puzzled, asking, "Who were these writers with their pompous rhetoric and their learned notes? No book can be named with certainty."[6]

For a work "above all . . . written with a home town audience in mind"[7] to resort to such scholarly display without a clear local target suggests indeed that the authors had not yet found their footing, and that at best they were diminishing their subject, employing the manner of a mock chronicle to place their little society at the end of cosmic processes. A more sophisticated view might add that the Irvings were also positing that their history's prelude does not rest on the rock of shared myth but upon the shifting sands of 18th century cosmological speculations. Though this interpretation fits nicely William Hedges' claim that the "*History of New York* consistently ridicules the possibility of acquiring certain or reliable knowledge," finally "reducing history almost to blank enigma," it does not address that nagging historical question.[8] The Irvings claimed to have histories in mind. If they did not, why did they make the claim, and why did Washington repeat it when he revised the book almost forty years later?

Is there no author in the Irving neighborhood whose pedantic display might have provoked that satire-producing admixture of "prejudice and rooted dislike"? Since the *History* is dedicated to the New York Historical Society, that venerable institution is a good place to look for someone addicted to amassing scholarly references. Samuel L.

Mitchell may be a candidate, since he was an eccentric historian with broad academic interests; however, while he may have represented the pedantic mental cast of the establishment to the Irvings, his *The Picture of New York,* which is cited in the *History,* does not contain the sort of notation used in Book One. While Mary W. Bowden may be correct in asserting that there is significant "satire in Knickerbocker's *History* of the type of men who founded the New York Historical Society, if not the founders themselves,"[9] the Irvings specified works rather than types; therefore, further search for one whose scholarly practices in a published volume approximate those attacked in the *History* is necessary.

Besides Mitchell, another prominent member of the New York Historical Society was the Rev. Samuel Miller (1769-1850), an important Presbyterian clergyman. In 1797 he began to collect materials for a history of New York, and he was given permission to make copies of documents without fee by an act of the legislature in 1798. According to his son, he "labored long in a desultory way" on the project and only gave it up in 1813 when he departed for Princeton, where he had a distinguished career as professor of church history.[10] This research interested him in founding the New York Historical Society (1804), for which he was Corresponding Secretary at the time of Washington Irving's appointment to membership. One of his discourses was the first historical article published by the Society.[11] Since Miller never finished his history, Michael Black has advanced a cogent argument that "Irving . . . was competing historically with an official historian, and when he won, or realized he was going to win, he laughed at the loser and those who supported him."[12] Thus Miller may be seen as a target, not on the basis of what he wrote, but because of what he didn't write: a definitive history of New York, for which he had collected masses of information.

An additional reason for Miller to have been attacked may have been his loyalty as "a warm partisan of Mr. Jefferson's politics and administration as President," a point of view likely to spark "rooted dislike" in the Irvings.[13] But more significantly, he did produce a major work which contains all of the scholarly apparatus mocked in the *History:* the two-volume *A Brief Retrospect of the Eighteenth Century* (1803), which gave its author a local and international reputation and a legitimate claim to the title of America's first intellectual historian.[14]

Originally the *Retrospect,* which was conceived as a sermon on the turn of the century, was to have covered all aspects of the eighteenth century, including theology, morals, and politics; though this design was never completed, the two volumes encompass twenty-four areas, including such subjects as physiognomy and Oriental literature. It was necessarily a patchwork job, an encyclopedic compilation which compensated for lack of depth with extensive notes, which the Irvings may be parodying in Book One. In applying the methods of the intellectual historian Miller comments that science in the eighteenth century "led to the erection and successive demolition of more ingenious and splendid fabrics" (*Retrospect,* I, 417). The Irvings make an interestingly similar remark that "philosophers demolish the works of their predecessors, and elevate more splendid fantasies in their stead, which are in turn demolished and replaced by the air castles of a succeeding generation" (*History,* p. 33). Though Miller expended great energy in the effort to compare these theories as a worthwhile historical enterprise, the Irvings reduced the endeavor to absurdity, through both the context of the mock chronicle and its tone.

All of the speculations on the origin of the earth mentioned in the *History,* with one exception, are also found in the *Retrospect.*[15] Note the likeness of the treatments of Buffon's ideas: "A comet falling into the body of the sun with great force, struck from its surface a large mass of liquid fire . . . This fragment forms the globe we inhabit" (*Retrospect,* I, 165). "This globe was originally a globe of liquid fire scintillated from the body of the sun by the percussion of a comet" (*History,* p. 29). Difference in tone may be noted in discussions of Whiston's theory: According to Miller, Whiston supposed "the earth in the beginning to be an uninhabitable comet, . . . in the form of chaos." The flood came about on account of another comet, which "involved our globe in its atmosphere and tail for a considerable time, and deposited its vapours on its surface, which produced violent and continuous rains" (*Retrospect,* I, 160). The *History* states, the earth "was originally a chaotic comet . . . The philosopher adds, that the deluge was produced by an uncourteous salute from the watery tail of another comet; doubtless through sheer envy of its improved condition" (*History,* p. 29).

Miller concluded that eighteenth century science provided orthodox religion with tools to defend the Bible as an historical document: "Every sober and well-directed inquiry into the natural history of man, and of the globe we inhabit," he writes, "has been found to corroborate the Mosaic account of the Creation, the Fall, the Deluge, the Dispersion, and the important events recorded in the sacred volume" (*Retrospect,* I, 434). While the *History* also supports the Mosaic account (pp. 24, 37), its tone in discussing exploration's contribution to revelation is markedly different from Miller's. The *Retrospect* concluded that

> "the geographical discoveries of the last age have contributed to illustrate and confirm Revelation. Behring and Cook were before-mentioned as throwing light on the population of the New World, and thus tending to support sacred history. But besides these, the knowledge gained by modern voyagers and travellers, of the manners, customs, and traditions of different nations, especially those on the Eastern Contient, has served to illustrate the meaning and unfold the beauty of many passages of scripture, before obscure, if not unintelligible" (*Retrospect,* I, 357).

The Irvings

> "should not be surprised if some future writers should gravely give us a picture of men and manners as they existed before the flood, far more copious and accurate than the Bible; and that, in the course of another century, the log-book of the good Noah should be as current among historians as the voyages of Captain Cook, or the renowned history of Robinson Crusoe" (*History,* p. 39).

Circumstantial and textual evidence, then, point to *A Brief Retrospect of the Eighteenth Century* as a likely target for the Irvings: In subject matter and method it closely parallels sections of Book One and is authored by a local historian of importance. But what was their point? Perhaps, following Professor Black's lead, it was that were Miller ever to finish his history of New York, his pedantry would drive him to preface it with the history of the world. In fact, this is what he had done, since for six years prior to the *Retrospect* he had been working on a history, but produced instead a compendium of virtually every area of human acivity except what went on in New York.

The satire may also strike yet closer to home. Miller was the pastor of Irving's father's church. Young Washington—and presumably his brother Peter—disliked the gloom of the frequent prayer sessions to which his father subjected the family. Though Washington never mentioned Miller, it may also be likely that he rebelled against some of the minister's attitudes toward the vocation which drew him: writing. For example, at the same time that Miller accurately analyzed the failure of America to excel in the arts owing to its commercial spirit, he contended that only one novel out of a thousand might be worthwhile, and the others constituted a criminal waste of time (*Retrospect,* II, 173-74).

If, as Charles Dudley Warner wrote, "The bent of Irving's spirit was fixed in his youth, and he escaped the desperate realism of his generation," it was in reaction to a society which would value him more as a lawyer or businessman than as a writer of fiction.[16] Though he would escape family pressures to go into law or business and turn writing itself into a business during his seventeen year sojourn in Europe, in 1809 Washington Irving was a young man for whom Samuel Miller probably represented established, practical values. In the seemingly irrelevant passages on the creation of the world the two brothers may have been quietly rebelling against an intellectual, religious, and social order which excluded so much of the fun which the *History* provided, mocking a figure of authority for the New York Historical Society, the church, and perhaps the Irving household.

Notes

[1] "'The Sketch Book of Geoffrey Crayon, Gent.,'" *The North American Review*, 9 (September, 1819), p. 345.

[2] "Washington Irving's Place in American Literature," *The Sewanee Review*, 14 (1906), p. 174.

[3] "Washington Irving" in *Classic Americans* (New York, 1931), p. 86.

[4] Washington Irving, *Deidrich Knickerbocker's 'A History of New York,'* ed. Stanley T. Williams and Tremaine McDowell (New York, 1927), p. 15. References within this paper are to this edition.

[5] *Knickerbocker's History of New York* (New York, 1848), p. 1.

[6] Williams and McDowell, p. xxi.

[7] Mary Witherspoon Bowden, "Knickerbocker's *History* and the "Enlightened" Men of New York City," *American Literature*, 47 (May, 1975), p. 159.

[8] *Washington Irving: An American Study, 1802-1832* (Baltimore, 1965), pp. 72, 108.

[9] "Knickerbocker's *History*," p. 163.

[10] Samuel Miller, Jr., *The Life of Samuel Miller* (Philadelphia, 1869), I, 110.

[11] *Life*, I, 276.

[12] Michael L. Black, "Political Satire in Knickerbocker's *History*" in *The Knickerbocker Tradition: Washington Irving's New York*, ed. Andrew B. Meyers (Tarrytown, 1974), p. 80.

[13] *Life*, I, 131.

[14] The best study of the *Retrospect* is Gilbert Chinard's "Progress and Perfectibility in Samuel Miller's Intellectual History" in *Studies in Intellectual History*, ed. George Boas (Baltimore, 1953).

[15] The Irvings recount the theories of Buffon, Hutton, Whiston and Erasmus Darwin with some detail. Burnet, Woodward and Whitehurst are mentioned. Only Darwin is not found in Miller.

[16] "Washington Irving," *The Atlantic Monthly*, 45 (March, 1880), p. 408.

INTEGRATING FINITUDE: THE EXPERIENCE OF TIME IN PROUST AND EINSTEIN

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Time for you and time for me,
And time yet for a hundred indecisions,
And for a hundred visions and revisions,
Before the taking of a toast and tea.

T. S. Eliot, "The Song of J. Alfred Prufrock," 1915

Everywhere, this second has already been replaced by another second, in a sequence frozen forever. Such a view appeared all the more convincing with the establishment of Standard Time at the turn of the century—all around the globe time was coordinated.[1] From an unused future, existence moves universally towards a shadowy past and ultimately dissolves in the darkness of the forgotten.

In the era that established Standard Time, the work of a novelist, Marcel Proust, and a physicist, Albert Einstein, liberated time from its foreordained tracks. After an active social life in the Parisian salons, Proust, in 1909, began his novel, *À la recherche du temps perdu,* and devoted the rest of his life to its writing. In 1905, the unknown Einstein, working in the Swiss Patent Office, published a short paper, "On the Electrodynamics of Moving Bodies," which initiated the special theory of relativity. Although Proust was aware of Einstein's theories, which gained popularity in France after the First World War, they did not exercise a direct influence on him for the following reasons: 1. he conceived his work before they were popularized; 2. in spite of his admiration for Einstein, he found the language of his theories too unfamiliar.[2] Affinity, rather than influence, defines the relation between these two thinkers.

For both Proust and Einstein, time does not flow in a neutral course but depends on the experiencer. Here, experience means more than just what is empirically present to the perception; it refers to the way man situates himself in the world. Keeping this distinction in mind, the present study pursues the question: how, in the work of Proust and Einstein, does one experience time? While Proust's novel describes qualities of time—the past, present, and future, as related in memory, Einstein's theory delimits quantities of time as measured by a clock. Nevertheless, both present time as an experience of finitude, a finitude which integrates the experiencer in his history and world.

In the long tradition of the quest theme in Western literature, Proust entitles his work, *À la recherche du temps perdu,* which one critic translates, freely but significantly, as *Quest of Time Lost.*[3] Proust once told an interviewer that, "we have both plane and solid geometry—geometry in two-dimensional and three-dimensional space. Well, for me the novel means not just plane (or plain) psychology but psychology in time. It is this invisible substance of time that I have tried to isolate."[4] Proust's quest unfolds within three perspectives: those of the protagonist, narrator, and author. Suffering, changing, and growing, the protagonist, called Marcel, has an immediate interaction with the present. The narrator recounts the growth of Marcel. Throughout the narrative, he observes him moving in the past like a man watching at night the light which left a star years ago. In the last volume, the narrator and his former self, Marcel, merge. The author, Proust, describes Marcel's movement towards the narrator, and then, their merging at the moment when he can pronounce the quest successful.

All three, Marcel, the narrator, and Proust, encounter time through memory. The importance of memory becomes evident in the English title of the novel, *Rememberance of Things Past*. Neglect of memory and the different kinds of memory affect the experience of time. Thus, unaware of its power, Marcel feels imprisoned in time: he lives the hours, days, and years, as they come and pass by, leaving him with a sense of emptiness and waste. But in certain unexpected moments, through the grace of involuntary memory, he relives past events as if they were taking place in the present. When he realizes the significance of these moments, he reaches the insight which the narrator has: now, both have the same experience of time. Although Proust depreciates voluntary memory in favor of involuntary memory, to create a novel of such structural magnitude requires both kinds.[5] The quest which starts with remembering ends with creation.

Time is regained in the creative act. Marcel relives the past as an actuality within the context of the present—this relation between the past and present endows both with a new meaning, for, to use the words of T. S. Eliot, "the past should be altered by the present as much as the present is directed by the past."[6] This active experience of the past in the present influences Marcel's future. Discovering his vocation, to be the artist who writes down his quest, he takes hold of the future. Created by his past, the artist recreates this past. His work of art grounds the shifting perspectives of the past, present, and future.

Unlike Proust, Einstein, the physicist, defines time with a measuring instrument. For this purpose, an object with a rhythmic motion may serve as a kind of clock. From this viewpoint, the human body contains many clocks such as the one established by the heart beat. In the famous example of the time traveller who journeys in space at high speed, he returns to find his world has grown much older than he did. One may speak, in this context, of the human body or a clock interchangeably: the relativity of time affects both in a similar way. However, the present study, because it deals with experience, will refer to a human observer and not a clock.

Time, argues Einstein, depends on the observer measuring it. For an illustration, he stages a scene with three observers: the first one stands on a railway embankment; the second is inside a very long moving train; the third, whom Einstein does not mention, is the physicist himself who observes the other two.[7] The observer on the embankment, with whom the reader identifies, sees a flash of lightning at each end of the train *at the same time*. He supposes that if the observer in the train faced him at exactly the same point when he saw the lightning, then, the observer in the train too should be able to see both flashes *at the same time*. The observer-physicist finds fault with this supposition: for him, the two observers measure time differently because they have different frames of reference.

What the observer on the embankment overlooks is motion: "we cannot attach any *absolute* significance to the concept of simultaneity, but that two events which, viewed from a system of co-ordinates, are simultaneous, can no longer be looked upon as simultaneous events when envisaged from a system which is in motion relatively to that system."[8] Since the universe has no absolute fixed point, one always needs a frame of reference: "Every reference-body (coordinate system) has its own particular time; unless we are told the reference-body to which the statement of time refers, there is no meaning in a statement of time of an event."[9] Thus, the physicist has to define the frame of reference of every observer.

Within each frame of reference, time flows uniformly because all that exists within that frame undergoes the same degree of change in time. In the case of the time traveller, he and those he left on earth do not perceive the difference in their aging rate until they meet. Within the frame of reference of the ordinary observer on earth, a frame defined for practical reasons as the same for the whole planet, he can be deceived into believing that his experience of time refers to the ticking of his watch which must be uniform for everyone and everything. He values this measurement as reality and dismisses as subjective lived time (temps vécu), that primordial experience which precedes measurement.[10]

Einstein does not deal with lived time either; he too wants to measure, so to speak, an objective time, albeit a time that depends on a frame of reference. Nevertheless, for him, experience can play a role. At the age of sixteen, he wondered about the paradoxical experience of how light would look to him if he travelled with it at the same speed. The older Einstein concludes that "in this paradox the germ of the special relativity theory is already contained."[11] That a scientist formulates his conception in an abstract theory does not mean that it did not find its source in a representational, even if imaginary, construction.

Experience conceals as well as reveals time. Einstein usually illustrates his theories with representational constructions to show how experience may be deceptive; but then, in explaining the reason behind the illusion, the experience becomes illuminating. In the example under discussion, the observer, from his limited perspective on the embankment, supposes that his counterpart in the train sees the two flashes of lightning at the same time. Actually, the latter, because he is moving towards one flash and away from the other, sees the first flash and then the second. For the observer on the embankment to realize his mistake, he has to adopt the perspective of different frames of reference: his own and that of the train. This, of course, is what the observer-physicist does except that he seems to be nowhere and everywhere. How does he experience time? He can situate himself within the frame of reference of any observer, measuring time as his own but also relative to another frame of reference. If the universe were empty except for one observer, clearly, he could not notice any change in the flow of time. Measuring time in Einstein's theory is a participatory activity which joins interdependent perspectives.

For Proust and Einstein, man experiences time as the horizon of his finitude. In order to be aware of this finitude, he must have opened to him the possibility of seeing through it. The perspectives of Marcel and the narrator parallel that of the observer in the train and the one on the embankment: Proust structures his novel through the viewpoints of Marcel and the narrator; Einstein accounts in his theory for both observers. For the novelist and the physicist the experience of time does not annihilate the finitude of perspectives in one absolute flux but integrates them. Proust becomes the subject and author of his own life. He traces in thousands of pages the labor under finitude. Indeed, finitude dominates his work and life: he died before finishing the last volume, *Time Regained*. But he regains time, not just because, in the usual way, an artist seals his life in a work that may immortalize him, but more suggestively, because the life which the novel depicts discloses a vocation that changes that very life and makes the novel itself possible. The novel points to the integration of a fragmented self in a self-determined history.

Einstein's physicist dwells in an ordered finitude. Time does not stand over against him as an object but pertains to the process of observation itself. Nevertheless, he can measure the time of another observer, systematically. From within his perspective, he realizes that the other observer must see one, then, another flash of lightning. Einstein's theory insists on the observer's perspective, not as a contingent limit, but as a limit binding him to the world.

Both the writer and the scientist encounter in time their integrated finitude. Man belongs to a frame of reference from which he can never escape. Yet, from within this frame, he integrates himself in his history and world. He recognizes that his mode of existing is temporalized.

Notes

[1] On the establishment of Standard Time, see Stephen Kern, *The Culture of Time and Space: 1880-1918* (Cambridge, Massachusetts: Harvard Univ. Press, 1983), pp. 11-15.

[2]. For a detailed discussion of the question of influence, see John D. Erickson, "The Proust-Einstein Relation: A Study in Relative Point of View" in *Marcel Proust: A Critical Panorama,* ed. Larkin B. Price (Urbana: Univ. of Illinois Press, 1973), pp. 247-76.

[3] Robert Champigny, "Proust, Bergson and Other Philosophers," in *Proust: A Collection of Critical Essays,* ed. René Girard (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1962), p. 123.

[4] Roger Shattuck provides the complete text of the interview, in English, in the appendix to his *Marcel Proust* (New York: The Viking Press, 1974), p. 169.

[5] See Shattuck, pp. 119-24.

[6] T. S. Eliot, "Tradition and the Individual Talent" in *The Great Critics: An Anthology of Literary Criticism,* 3rd ed., eds. James H. Smith and Edd W. Parks (New York: W. W. Norton and Company, Inc., 1967), p. 715.

[7] *Relativity: The Special and the General Theory, A Popular Exposition*, trans. Robert W. Lawson (New York: Crown Publishers, Inc., 1961), pp. 25-7.

[8] Albert Einstein, "On the Electrodynamics of Moving Bodies" in *The Principle of Relativity: A Collection of Original Memoirs on the Special and General theory of Relativity* by H. A. Lorentz, A. Einstein, H. Minkowski and H. Weyl, trans. W. Perrett and G. B. Jeffery (New York: Dover Publications, Inc., 1923), pp. 42-3.

[9] *Relativity,* p. 26.

[10] On how one learns to live time as defined by a clock, see Leroy Troutner, "Time and Education" in *Existentialism and Phenomenology in Education: Collected Essays*, ed. David E. Denton (New York: Teachers College, Columbia University, 1974), pp. 159-81.

[11] "Autobiographical Notes" in *Albert Einstein: Philosopher-Scientist,* ed. Paul A. Schilpp (Evanston, Illinois: The Library of Living Philosophers, Inc., 1949), p. 53.

MARK TWAIN IN PERSON, 1885: READING IN WISCONSIN

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Mark Twain and his performing partner George Washington Cable devoted a week of their four-month tour during the 1884-85 lecture season to cities in Wisconsin: Janesville, Madison, LaCrosse, and Milwaukee. They appeared in Wisconsin only three weeks before the publication of *The Adventures of Huckleberry Finn.* Interest in Twain's new book was growing as a result of the long and highly successful lecture campaign, and Cable too was quite a sensation with his popular novels of Creole life and his vigorous public campaign for Black equality. Consequently, the two spoke to packed houses across the state and consistently received enthusiastic reviews from their audiences and from the newspaper writers who described the literary event in superlative phrases. The *Janesville Daily Gazette* called their performance "one of the best appreciated given in this city for a long time"; the *Wisconsin State Journal* in Madison said "the entertainment pleased all"; the LaCrosse *Morning Chronicle* pronounced the reading "decidedly the leading success of the winter." One critic has called the tour "the most celebrated reading tour of the decade"; this is the same as calling it *the* entertainment event of the 1880s.[1]

It is no coincidence that we are observing the centennial of *Huck Finn's* publication and a major lecture tour of Twain's career. This tour, his first lengthy stage schedule in fifteen years, was intended to generate sales for *Huck Finn* and raise money for his new publishing house. American publication came on February 18, 1885; *Huck Finn* had been published in England and Canada two months earlier in order to secure the foreign copyrights. Several chapters were serialized by *Century* in December and January to whet the appetites of readers. The lecture tour extended from the middle of November 1884 to the end of February 1885. After a weekend performance in Chicago, Twain and Cable then read in Janesville on January 20th, Madison the 21st, LaCrosse the 22nd, St. Paul, Minnesota the 23rd, Minneapolis the 24th (Sunday the 25th was an off-day), Winona, Minnesota the 26th, Madison again on the 27th, and Milwaukee the 28th and 29th; they then returned to Illinois for readings in Rockford and Chicago. In larger cities like Milwaukee and Chicago, the two would speak on consecutive nights; otherwise, they performed an exhausting schedule of one-nighters. Even Sundays, when Cable refused to work or travel, were hardly restful for Twain. He complained bitterly that Cable's piety actually aggravated the tiresome routine, because Twain could never rest on a day when he performed. During the week the authors usually were traveling and working every day. Twain did make money on the tour and, more importantly, helped stimulate a large first-sale for *Huck Finn,* but he worked considerably harder on the tour than he had planned and, understandably, refused his business manager's proposal to extend it another month. There was never any problem in finding bookings.

Twain's stage performances, part of the marketing for *Huck Finn,* suggest how he wanted the book received. His selections from it are exclusively humorous: Huck and Jim discussing the wisdom of Solomon or the logic of having a separate language for Frenchmen; Huck and Tom planning their ridiculous "evasions" for freeing Jim; and the episode of the river tough fighting, already printed in *Life on the Mississippi.* Twain had considered a program from *Huck*

Finn alone but decided for more variety.[2] Still, he emphasized local color and humor, but not exactly satire. Notice that Jim is likely to be simply a clown in these stage readings. Twain on stage seemed rather like the man who wrote the headnote to *Huck Finn* demanding no serious moral interpretations.

The emphasis on humor from Twain was wise publicity, of course. But in larger context, the tour itself was still part of the long creative process that produced *Huck Finn,* a book which transcends mere entertainment, and marks a change in the direction of Twain's career. He was revisiting his youth in towns where he once lived—Hannibal, Missouri and Keokuk, Iowa, for example—as he had done in 1882 to finish *Life on the Mississippi.* Furthermore, Cable, a friend for two years now, was certainly an influence on Twain's thought. He was best-known, in fact, as a Southerner speaking out against the South for its racism. His latest book had suggested that the South's losing the Civil War was a fortunate outcome. Moreover, Cable actually had helped set the groundwork for *Huck Finn's* reception by breaking from the unofficial literary tradition of Southern apology for slavery and the war. Two years earlier Twain's most biting comments on Southern culture written for *Life on the Mississippi* had been suppressed. (Cable also encouraged Twain to read Malory's *Morte D'Arthur,* and some of his first notebook entries on *A Connecticut Yankee in King Arthur's Court* appear during the tour.) Cable's part in sharpening Twain's social criticism has never been fully explored. Shortly after the tour was finished, Twain wrote a letter, recently discovered, in which he promises to pay tuition and board for one of Yale University's first Black law students.[3]

This lecture tour of the two reconstructed Southerners is also interesting as a portrait of Twain, not just as a footnote to the publication history of *Huck Finn.* It was one of the few (and maybe last) times in Twain's life when everything seemed to be going well for him. His marriage was happy, his reputation as a writer was established, and he was socially and financially secure. At age fifty, Samuel Clemens was a success, before family tragedies and financial difficulties impelled his creative talents toward social invective. A middle-aged man now, everything he wrote sold. He was comfortable with his work and his audience, and they were comfortable with him. He was "Mark Twain" to them, the humorous writer from the American frontier, recognized as such and generally pleased by his reputation. He did once, at least, complain to Cable that he was cheapening himself as the humorist only, but any dissatisfaction with his public role never came through his stage performances.[4] At the height of his career as Mark Twain the funnyman, the author had no trouble staying with that public persona. His creative talents, too, were at a high point all through this four-month tour.

Twain varied his readings somewhat so that his performance was always fresh and so that he would not repeat himself too much for return audiences. He was especially unhappy and bored when Cable did not change his readings. In his Wisconsin appearances, Twain's selections from *Huck Finn* were read with "The Awful German Language," "The Jumping Frog," "A Desperate Encounter with an Interviewer," and the ghost story of "The Golden Arm." Advertisements and programs usually left his concluding piece open, and Twain often tried to choose something appropriate to his audience's particular responsiveness. After a few unsuccessful attempts at simply reading early in the tour, Twain spoke from memory, a delivery which reviewers usually noted with compliments. On stage, before this tour, Twain had presented original lectures and read sparingly.[5] Now, he intended mainly to read material published or already set in print, but he was always careful to adapt his material for a vocal stage delivery.

This off-hand manner of delivery increased his casualness and spontaneity and also helped audiences perceive him—as he wished—as a natural story teller, a born wit. His humor was "dry, unconscious, apparently spontaneous," said the Janesville *Daily Recorder.* "He never smiles when telling a story that causes his audience to laugh until tears trickle down their cheeks, but on the contrary, pulls his iron gray moustache and scowls," but, "He put his audience in good humor with the first sentence and it continued until the last." The *Janesville Daily Gazette* published a preview which described Twain's delivery as "a dry, earnest manner, as though he really believed . . . the ludicrous situations . . . and expected his listeners to." The *Wisconsin State Journal* said Twain was "active in his movements . . . [but] carelessly," like "some awkward overgrown boy. The expression of his face scarcely changes during an entertainment, though when the audience laughs intrude there is the greatest air of injury about it."

His delivery was always studied, however, just as he describes his formula in "How to Tell a Story." Twain was a careful performer, and he received enthusiastic responses which justified the rather steep admission prices of fifty cents, seventy-five cents, and a dollar. Incidentally, the prices never varied, except that sometimes a good auditorium had no fifty-cent seats. Twain was going out to make money. Now, a river city like LaCrosse was probably economically more prosperous in 1885 than in 1985, compared to other cities in the state; but, even so, packing the local opera house with a thousand people strained more people's incomes there than in Chicago or Milwaukee. Still, not one newspaper writer anywhere in the state complained about the admission cost; in fact, writers usually complained about the audiences or auditoriums, if they were not suitable for such an important literary event. The LaCrosse *Chronicle* and Milwaukee *Evening Wisconsin* particularly noted that people arriving fashionably late were disturbing the performers and disrupting the show. The *Wisconsin State Journal* and Janesville *Daily Recorder* said the theater was too hot or too cold. But no one ever said that the spectators did not get their money's worth, even though Twain himself privately expressed doubts on occasion.

Cable usually spoke first (Twain particularly hated to work to an unsettled house). The two then took turns on stage and varied the tempo and tone of the program. Twain was the humorist and Cable the serious social commentator. The Janesville *Daily Recorder* said Cable's appearance and delivery denoted "intelligence . . . and the gestures and movements of a polished gentleman," while "Twain's every moment [on stage] was indicative of the droll humor that was fairly bubbling out of him." The paper concluded, "They are both stars of no little magnitude in their specialties."

These roles were deliberately complementary. By design, Cable was to portray moral sentiment and edifying thought, Twain to evoke uncontrolled laughter. Twain was the better-known personality, but he was known principally as a comedian and performer, and Cable actually enjoyed the reputation of being the more literary man.[6] Reviews often sounded as though they were paraphrasing the advertisements, which promised "superb fun" and "wit" from Twain and "exquisite humor and pathos" from Cable. The LaCrosse *Chronicle* dutifully reported on Twain's "grotesque humor" and Cable's "delicate pathos." the *Janesville Daily Gazette* promised viewers "sentiment, pathos, and delicate touches of humor" from Cable and "the wildest flights of hyperbole" from Twain, "superbly droll and outrageously extravagant."

Twain always received top billing in the advertisements; it was his tour, of course, and Cable worked on salary from him. In addition, Twain always received more praise as an entertainer when the two were reviewed together, but Cable was not slighted or criticized. It was not uncommon for a reporter to give more space in a review to Mark Twain's doing and sayings but to reserve his chief accolade for the art of Cable's writing and reading—appropriate for their intended roles, Cable the thoughtful literary artist and Twain the natural "character."[7] For instance, the Janesville *Daily Recorder* called Cable "a good elocutionist and a man of literary ability," but Twain was simply unique "in his inimitable style." Occasionally, there was feature material in papers on Cable's social thought. Both the *Wisconsin State Journal* and the *Milwaukee Sentinel* printed some correspondence between a Black resident of Wisconsin and Cable in which he (by implication, the papers too) stressed the necessity for cultural assimilation. In addition, the *Madison Daily Democrat* reviewed only Cable to emphasize his social beliefs.

This lecture tour was a literary event, but one finds that local papers showed their biases in characterizing and complimenting the performers. The tour was front-page news both in Madison and LaCrosse, for example, but in the state capital it was Cable the reformer featured on page one, and in the river town it was the unruly former steamboat pilot. The LaCrosse *Republican and Leader,* for instance, wrote about Twain's restlessness, his constant smoking, talking, and moving among train cars as though he was particularly uncomfortable about traveling in civilized society. However, in Milwaukee, the *Evening Wisconsin* and *Sentinel* featured stories on Cable because he had based characters in his Civil War novel on people then living in that city. The largest press coverage, about two columns each, was in papers for LaCrosse and Milwaukee. Twain had been in LaCrosse as a traveler and described it favorably in *Life on the Mississippi,* although this is not mentioned by the *Chronicle* reporter. Three years earlier the paper had written about Twain's brief stop. It is easier to explain the interest of the *Milwaukee Sentinel* and *Evening Wisconsin.* In addition to whatever civic pride they may have had, the two dailies competed for news and feature material about the season's biggest literary event, one interviewing Cable and the other Twain.

The critical reviews were always uniformly favorable although some of the uniformity borders on plagiarism. One of the stories in the *Wisconsin State Journal* contains a paragraph that is copied almost word-for-word from the *Janesville Daily Gazette* of the day before. Of course, this was within the limits of usual journalistic practice a hundred years ago and constitutes only an endorsement of the first review. Twain's selections usually were reviewed at greater length than Cable's. Usually, however, papers refrained from detailed description of the entertainment. One particularly effective piece which was summarized a few times was "The Awful German Language," in which Twain said that he would rather decline two drinks than one adjective, a fairly literary joke to cite. "The Golden Arm" was described in several papers, showing how Twain could methodically lead his listeners to the sensational conclusion of the story when everyone jumped at the ghostly accusation, "You've got it!" On the whole, papers quote sparingly; in fact, the LaCrosse *Chronicle* reporter observes that the local audience was familiar with these two popular writers. Reviews usually describe manner of delivery and appearance more than content. The emphasis, especially for Twain, is more on the literary "character" of the author rather than any particular work.

The Janesville *Daily Recorder* pronounced the entertainment the "literary event of the season"; Twain in particular was "enthusiastically received." According to the *Janesville Daily Gazette,* "Mark Twain, from his first bow to the close of the entertainment, kept the audience in continued laughter, while Mr. Cable was listened to with deep interest." The *Madison Daily Democrat* quoted a press review from St. Paul: "The audience laughed only once during the evening, but that was from 8 o'clock till 10." The dry understatement of this observation was typical in a way; general pronouncements on the readings often came in cliche-like superlative praise, but for description reporters sometimes tried to imitate Twain's comic style.[8] So it was that the reporter for the LaCrosse *Chronicle* noted the disparate appearances of the two authors and said, "Such a pair—such a team, let us say—in animal life, would make a horse laugh. But they pull well together."

Twain's appearance and stage delivery were suited for the image he wanted to project of a completely artless, unselfconscious wit. The Milwaukee *Evening Wisconsin* said he "carelessly and indifferently sauntered upon the stage" and read "[w]ithout ceremony." The *Wisconsin State Journal* called his stage style a dry recital" which nonetheless "kept the audience in a constant roar of laughter." The LaCrosse *Chronicle* said, "He comes upon the stage as though looking for a pin on a floor covered with eggs." Then, "Speech falls from his lips as though against his will." Finally, "He disappears with a canter and if he had not said a word, there would still be something to laugh at."

In physical appearance, the LaCrosse paper said, he was "tall, stooping, shambling of gait with tumbled hair and uncertain moustache, the counterpart of nothing except his odd self." Other papers reported the same. The Janesville *Daily Recorder* noted that he was "tall, awkward, with heavy bushy hair . . . heavy moustache . . . and he drawled his words out." Reporters and audiences came to these readings with an image of Twain derived from his books, and Twain was always in character for them. The *Winona Daily Republican* even headlined its story "Innocents Abroad" and noted Twain's movements as "side-long, awkward stride, amusing in itself . . . [with] a natural and easy force to his gestures."

Everywhere Twain spoke in Wisconsin he had a full house; often he sold out before the night of the performance. The *Wisconsin State Journal,* on his second stop in Madison, thus promised an entertaining night for "people [who] were not able to secure seats" at the first. "These two gentlemen are drawing marvellously wherever they appear," it said. And every audience called for encores; Twain offered two encores in LaCrosse. Cable too was usually recalled to the stage, but he always allowed Twain to finish the program if any encores were called for. Twain never explicitly insisted upon this, but he clearly wanted to remain the star attraction of the tour.

The apparent success of the tour at all stops in Wisconsin and Minnesota gave no hint of troubles in the background. In fact, Twain was not entirely pleased with receipts and blamed his business agent, nor was he pleased with Cable over the course of time. Cable's unwavering Sabbath piety irked Twain. Cable had started out encouraging Twain to accompany him to church services and reading his Bible to him on the train, both of which he diplomatically discontinued when Twain ignored him. Cable never swore or smoked, although there is no record that he ever upbraided Twain for these favorite hobbies of his. Worse, perhaps, Cable would not play billiards with Twain. Cable's expense account was a bit rich for Twain, and, worst of all, his time on stage seemed too great. These are all complaints which Twain often wrote to his wife, particularly often after the new year began and the tour went into the mid-west. He seems to have kept his complaints to himself on the tour, however; at least Cable did not record any awareness that Twain was growing irritated with him. In fact, Twain did not continue any criticism of his partner after the trip ended—actually he called him a perfect traveling companion—and it is reasonable to say he simply lost patience at times for all the traveling and work, and for the January weather in Wisconsin. From Madison, Twain wrote that he was cold in his hotel. In LaCrosse, his business manager noted that he was "a little sharp" with people at the train depot. In Milwaukee, Twain tried a hot bath before going on stage in order to refresh himself, but this apparently only tired him more. Twain actually confided to Cable that he felt the second night in Milwaukee was a disaster.[9] Twain and Cable generally suffered from nothing worse than weariness, cold, and occasional impatience with each other, but their manager suffered a mild heart attack in Madison and had to be left behind in Milwaukee to recuperate. The *Evening Wisconsin* noted the agent's illness but not how heavily it actually weighed down the spirits of the two performers.

From what one can know of the background to this lecture tour, already almost three months long, it is remarkable that Twain always managed to stay "on stage," so to speak, for local audiences and reporters. For instance, a *Milwaukee Sentinel* reporter sent to interview Cable went mistakenly into Twain's room and found him "decidedly en dishabille." His "afternoon attire" was "a long white nightshirt . . . and a cigar." In effect, Twain was discovered with his pants down, but he corrected the reporter's directions and played up to his amazement with obvious pleasure. In Madison, "about twenty" people followed Twain and Cable to their hotel. Cable came down from his room and greeted each one individually and politely, even though "he expected to meet but two or three," according to the *Wisconsin State Journal.* Twain only sent his regrets by Cable, and the paper granted him "a little needed slumber." Apparently, no one felt slighted.

Twain did grant an interview to a reporter from the *Evening Wisconsin* in Milwaukee, who found him quite agreeable despite showing obvious signs of the cold weather. Twain had read his imaginary "Desperate Encounter with an Interviewer" in Milwaukee, and the *Evening Wisconsin* reporter was perhaps a bit unprepared for the urbane person he actually met. He described Twain as "brusque but genial . . . the result of the varied life he has led." Twain told him that he enjoyed the lecturing, was pleased by the size and responsiveness of the crowds, and was living a hermit-like existence in Hartford, Connecticut. The reporter described Twain's former wild occupations of steamboat pilot, miner, and traveler. He had had "a rough experience generally," the writer noted, but was only the more admirably masculine for it—an "almost perfect specimen of physical manhood," American frontier character. Twain politely discussed the need for international copyright, his sales of books to date and hopes for *Huck Finn,* and a rather embarrassing bit of publicity for the new book which had leaked out. An engraver had created an obscene illustration out of one woodcut for the salesmen's advance copies of *Huck Finn,* which Twain casually dismissed as "a slight gouge of a graver . . . an indelicate addition to . . . one of my characters." (It was an erect phallus added to a sketch of Reverend Silas Phelps, with Aunt Sally apparently staring at it amusedly and asking, "Who do you reckon it is ?")[10] Twain said that all adulterated copies of the book had been suppressed, and no one need fear finding any obscene illustrations.

In general, no news during Twain's week in Wisconsin showed any hint of the weariness and irritation Twain expressed privately about the long tour and his traveling companions, nor any of his anxiety about preserving his reputation for humor and decency while *Huck Finn* was going to press. The lecture tour was a success in the most important way for Twain; Samuel Clemens was able to remain Mark Twain without fail for over four months. The newspapers usually call him Twain, a tribute to the currency of the literary character he made of himself. The LaCrosse *Chronicle* writer could not even spell Clemens correctly, and the *Milwaukee Sentinel* reporter who was introduced to Mr. Clemens immediately called him Twain. Without exception, newspapers emphasized the colorful, vivid, and entertaining man—just the image Twain cultivated.

NOTES

[1] Fred W. Lorch, *The Trouble Begins at Eight: Mark Twain's Lecture Tours* (Ames: Iowa State University, 1968) 164. Since constant footnoting or even parenthetical references to dates of all newspapers quoted here would simply be intrusive, I have foregone this documentation. With the itinerary in the following paragraph, anyone who wishes to find specific stories can do so easily. All Wisconsin papers are available on microfilm in the State Historical Society, Madison.

[2] Lorch 165.

[3] See Guy A. Cardwell, *Twins of Genius* (East Lansing: Michigan State University, 1953) 68-77. In addition, see the brief summary of Twain's letter to a dean of the Yale law school in *Time* 25 March 1985: 69.

[4] Cardwell 25.

[5] Lorch 162; Paul Fatout, *Mark Twain on the Lecture Circuit* (Carbondale: Southern Illinois University, 1960) 216; and Arlin Turner, *George W. Cable: A Biography* (Baton Rouge: Louisiana State University, 1966) 177.

[6] Cardwell 17; and Fatout 205-06, 216-17.

[7] Fatout 222; and Turner 188.

[8] Cardwell 29.

[9] See Cardwell 49; Fatout 211-12; Lorch 174; and Turner 180.

[10] See Walter Blair, *Mark Twain and Huck Finn* (Berkeley: University of California, 1960) 364-67.

SOME EFFECTS OF CLEARCUTTING ON SONGBIRD POPULATIONS IN THE NORTHERN HARDWOOD FOREST

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Abstract

A study was conducted in Marinette Co., Wisconsin on the breeding bird diversity occuring in six northern hardwood forest stands; 3, 5, 11, 17, 35 and 45 years of age. Breeding bird censuses were conducted along one to several transects in each of the stands in 1976 and 1977. A trend was observed in which diversity was low in the 3 year old stand and increased to a high in the 11 year old stand followed by a decline toward the 45 year old stand. The trend in bird species diversity was not correlated with vegetation density, plant species composition, or plant species diversity in any of the stands.

Introduction

Today, the term forest resource has taken on a much broader meaning than just timber. The current concept also includes, water, wildlife, range, and recreational resources of the forest. Forest managers as well as the public are seeking more precise information about the effects following different uses in specific forest situations.

In terms of species composition and structure of vegetation, windfalls and fires have altered much of our forest habitat many times in the past. However, the effects on fauna of such management practices as clearcutting may differ greatly from those occurring after storm fellings and burns (Ahle'n, 1975).

Clearcutting (removal of all standing timber) has been carried out in one form or another since settlement of this country. Ward (1974) believes that virtually all hardwood forests in the northeastern United States have sustained two or more clearcuts.

Aspen regeneration requires some type of disturbance so that clearcutting is the silvicultural practice most often utilized for the propagation of this forest type. Because the aspen-birch forest type is the most important source of pulpwood in Wisconsin (and other Lake States) and represents nearly 4 million acres (Spencer and Thorne, 1972, Giese, et al., 1976) there is no doubt that clearcutting represents an important perturbation in Wisconsin forests.

Some of the public resentment toward clearcutting relates to physical impact such as poor road placement and severe erosion. However, it is evident that much of the recent public concern about timber cutting practices can be traced to its visual impact (Lang, 1975, Giese, et al., 1976). It is because of this public reaction that more emphasis is being placed on quantifying the effects of clearcutting on flora, fauna, soils and other environmental parameters. Forest managers, whether public or private, also need to know precisely what effects the size of the area being clearcut has on various wildlife species and their densities (Severinghaus and Tombaugh, 1975).

A few studies concerning animal populations, aesthetic impacts and other non-silvicultural parameters, with respect to clearcutting, were begun in the early 1960's. Federal hearings in 1972 on forest management practices resulted in increased research efforts. The effects of clearcutting on wildlife are largely unmeasured and not easy to quantify. As a result wildlife has not been adequately included in multiple-use management plans for forestry practices (Webb, 1973).

Because of their conspicuousness, territorial behavior, and well known systematics, birds have been commonly utilized in measuring the effects of the alterations in habitat resulting from logging operations (Odum, 1950, Jarvinen and Sammalisto, 1973). Several recent reports studied changes in bird species diversity following various amounts of logging on differing forest types: eg. Hagar, 1960; Conner and Adkisson, 1975; Adams and Barret, 1976; Webb, et al., 1977; and Ahle'n, 1975 and Asbirk, 1975.

Bond (1957) investigated breeding bird distribution in the upland forests of southern Wisconsin. Some recent studies on bird species diversity in Wisconsin have concerned campground bird communities (Guth, 1978) and avian utilization of small woodlots (Howe and Jones, 1977) but the effect of clearcutting on bird diversity has been little studied.

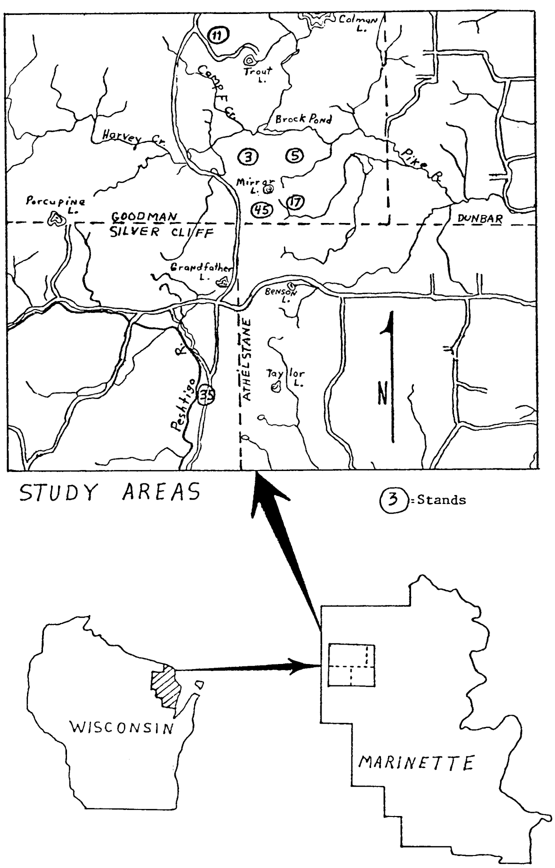

Fig. 1. Study area

This investigation was initiated to examine the changes which occurred in breeding bird populations as a result of clearcutting in the northern hardwood forest of Wisconsin. Goals of this study were to (1) document the change in breeding bird species composition as a result of clearcutting, and (2) to describe the relationship between bird species diversity and age of stand since cutting. The data presented here were gathered between April, 1976 and October, 1978.

Study Area

The study was conducted in the townships of Goodman and Silver Cliff in northern Marinette County, Wisconsin (Fig. 1). The vegetation of this region is composed of Hill's oak (*Quercus ellipsoidalis*), quaking aspen (*Populus tremuloides*), large-toothed aspen (*P. grandidentata*) with some white oak (*Quercus alba*). The importance of the aspen in this area is demonstrated by the fact that the aspen-paper birch (*Betula papyrifera*) type of commercial forest comprises 243.3 thousand acres (98,380 hectares) or 27.4% of Marinette County (Spencer and Thorne, 1972). The prevalent ground cover is *Aster macrophyllus, Carex pennsylvanica, Maianthemum canadense, Oryzopsis asperifolia, Pteridium aquilinium, Vaccinium angustifolium and Waldsteinia fragarioides.* Six aspen stands were selected for study; they were 3, 5, 11, 17, 35 and 45 years old. All six sites were within 6.5 kilometers of Mirror Lake. The 3, 5, 17 and 45 year old stands were in sections 30, 29, 31 and 31 respectively of R18E, T36N. The 11 year old stand was located in section 13 of R17E, T36N. The 35 year old stand was located in section 24 of R17E, T35N.

The 3, 5, 11 and 45 year old stands were the largest being approximately 90, 65, 50 and 140+ hectares respectively. The 17 and 35 year old stands were smaller in area being approximately 15 and 30 hectares respectively.

The topography is one of gently rolling hills with a total relief of 10 meters, as determined from USGS quadrangle maps.

The soils under the stands are mapped as sandy loams, originating from glacial drift and wind blown loess, with leached A horizons and tend to be acidic (Beatty, et al., 1964).

All of the areas studied showed indications of having been burned in the past, i.e., occasional charred stumps and burn meadows were observed on the sites. The method of cutting appeared to have been similar on all the stands. All standing timber, except for scattered live trees and dead snags, was cut down and usable logs removed. No scarification (scraping the soil clean) of the substrate was apparent, nor had logging residue been removed or burned. Logging residues were less evident in the older stands.

Methods

Vegetation Sampling

Density was sampled using 100 randomly located quadrats each $1m^2$ for herbaceous species and 40 randomly located $16m^2$ quadrats for shrub and sapling species. The point quarter method (Cottam and Curtis, 1959) was utilized for sampling trees greater than 4 inches DBH at 40 points in each stand.

Vegetation Analysis

Total basal area, relative frequency, relative density, relative dominance and importance value were calculated for all tree species on the 11, 17, 35 and 45 year old stands. A diversity index was computed for trees and shrubs as in Shannon-Weaver (1964). The formula is $-\Sigma_i P_i \log_e P_i$ where P_i equals the proportion of all plants which belong to the i^{th} species.

A shrub density index was computed for each stand by summing the individual densities for all the species in a given stand.

Avian Sampling

The strip census or transect method similar to Conner and Adkisson (1975), Gavereski (1976) and Milewski and Campbell (1976) was used to sample the bird species present. Randomly located transects 200 meters long were established in each of the 6 stands: 4 transects were established in the 3 year old stand, 3 in in the 5 and 45 year old stands and 1 each in the 11, 17 and 35 year old stands. Only one transect was established in 3 of the stands because of size limitations. Each transect was run 3 times, suggested by Emlen (1971) to be the minimum number necessary to derive valid population estimates on a transect.

Those birds heard singing or observed within 50 meters on either side of the transect were recorded. Censusing was conducted only on calm mornings to avoid bias due to wind interference in detecting singing birds. Several flags were tied at a distance of 50 meters from each transect to aid in identifying the boundaries of the sampling area. All transects were placed at least 50 meters from the edge of any given habitat type. All birds, breeders and nonbreeders, observed on the study areas were recorded. A factor of (2.0) was applied to the number of singing males in each census to estimate the total population including females. Counts were begun at 0600 and were concluded by 0900. Counts were not conducted on mornings that were heavily overcast or during periods of precipitation.

Avian Analysis

In the formula for species diversity (Shannon and Weaver, 1964), H is the bird species diversity index, P_i is the proportion of all individuals which belong to the ith species. This statistic includes both richness (number of species) and evenness (number of individuals of each species) factors and better expresses diversity than would a simple count of species number.

Richness values were also computed for each stand, utilizing $D = \frac{S-1}{\log_e N}$ (Margalef, 1958), where D is the richness value, S is the total number of species and N is the total number of individuals.

In addition, evenness values were computed, utilizing $e = \frac{H'}{\log_e S}$ (Pielou, 1966), where e is the evenness value, S is the total number of species and H′ is the bird species diversity index.

RESULTS

Vegetation Analysis

Species Composition—Observations indicated that the herbaceous vegetation was relatively uniform in all the stands, and thus herbaceous vegetation was sampled only on the 3 and 45 year old stands. Sorenson's similarity index (1948) of 82 for the 3 and 45 year old stands supports the observed uniformity of the herbaceous growth in the stands. These data, along with observations made on the remaining 4 stands, suggest that wood aster (*Aster sp.*) and bracken fern (*Pteridium aquilinium*) had higher cover and frequency than any of the other constituents in the herbaceous layer. The species contributing most to the shrub layer in terms of density was hazel *(Corylus americana)* (Fig. 3). Tree importance values (Curtis, 1959) are presented for the 11, 17, 35 and 45 year old stands (Table 1).

Quaking and large-toothed aspen were found to have the highest importance values (Table 1) of all the species present on any of

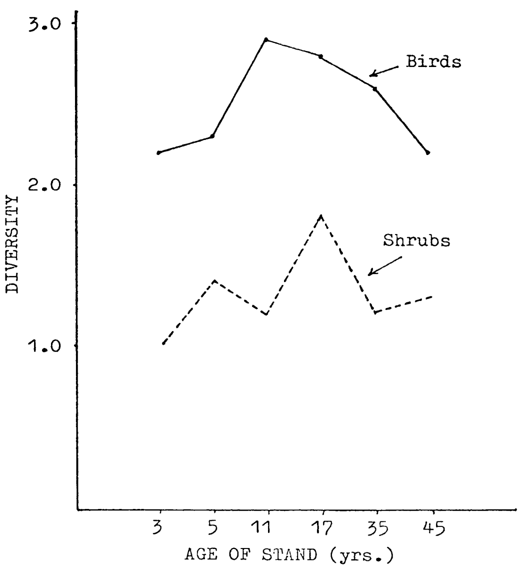

Fig. 2. Shrub diversity and bird species diversity plotted against age of stand.

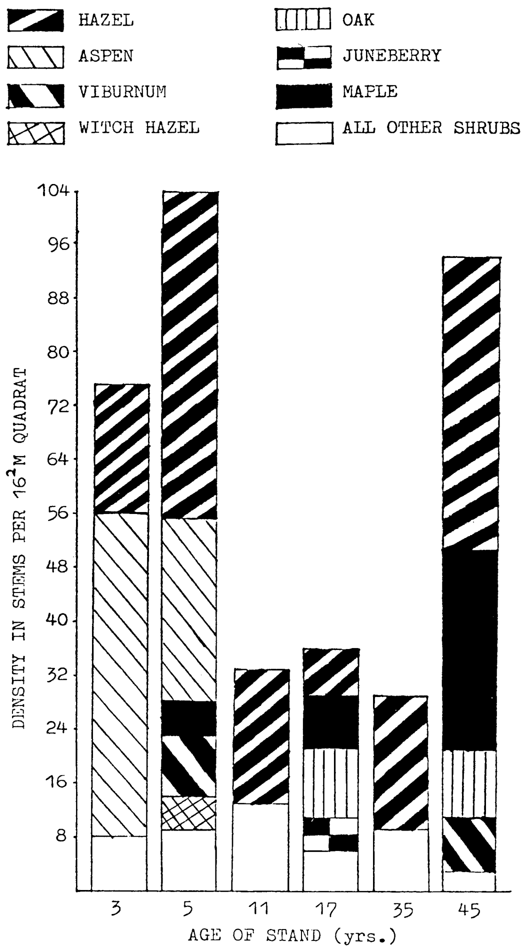

Fig. 3. Shrub layer species with densities greater than 5 stems per 16 sq. meter quadrat for the six study areas.

TABLE 1. Importance values for trees on the four older stands.

Species	*11 yr.*	*17 yr.*	*35 yr.*	*45 yr.*
Aspen	290.0	208.8	267.4	187.2
Hill's oak	—	49.9	8.4	42.9
Red maple	—	2.8	9.9	33.1
Paper birch	—	20.2	—	37.0
White pine	—	9.8	—	—
Jack pine	—	7.6	—	—
Red pine	—	—	14.9	—
Black cherry	7.4	—	—	—
Total	297.4	299.1	300.6	300.0

the stands. In the 3 and 5 year old stands these species were represented by saplings. Hill's oak and paper birch also had relatively high importance values for the 45 and 17 year old stands. The 11 year old stand had fewer tree species than any of the other three stands.

Foliage Structure—Although species composition differences were noted, the principle vegetational difference between stands was a structural one. While no foliage height diversity measurements were made on any of the stands, it became apparent from observations that foliage structure was different in each of the stands. These structural differences were in terms of fairly well defined layers of foliage as to height in the forest (Fig. 4).

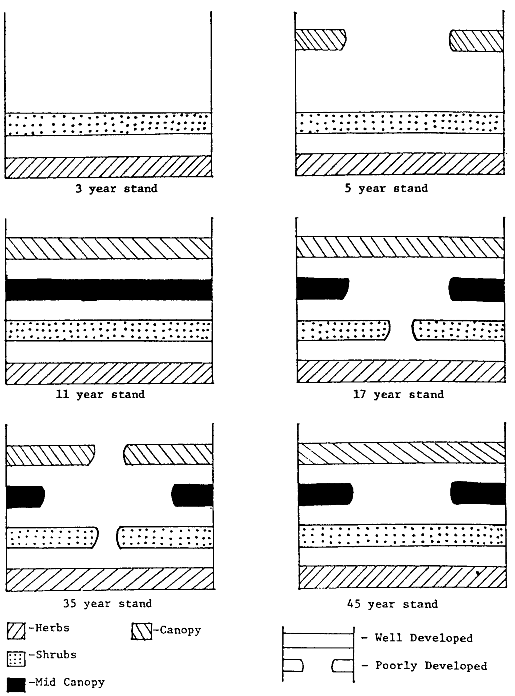

Fig. 4. Observed vegetational layering in the six study areas.

The 3 year old stand had only herbaceous and shrub layers. The shrub layer in this case was composed mostly of aspen saplings. The height of the canopy in this stand was measured at 2.0-2.5 meters.

In the 5 year old stand the sapling canopy was attaining sufficient height to begin establishing a third vegetational layer, a tree layer. The height of the canopy in this stand was measured at between 4.0-5.0 meters.

The 11 year old stand had the most complete layers of all 6 stands, as determined by visual observation, including herbaceous, shrub, mid-canopy and canopy layers. The mid-canopy layer was formed from pole-sized trees of aspen and black cherry (*Prunus serotina*) and tall shrubs such as Juneberry. This mid-canopy layer was located above the shrub layer and below the forest canopy. The height of the canopy in this stand was estimated to be 9.0-10.0 meters.

The 17 year old stand appeared less layered than the 11 year old stand in that the mid-canopy layer was less evident. The shrub layer in this stand was found to be relatively sparse. Because of this reduced shrub density the stand presented a much more open understory than the 11 year old stand. The height of the canopy in this stand was estimated at 10.0-15.0 meters.

Layering in the 35 year old stand was similar to the 17 year old stand with a more open understory. The canopy of the 35 year old stand was approximately 15.0 meters.

The 45 year old stand differed from the 35 year old stand in having a more developed shrub layer and a more closed canopy. The height of the canopy was approximately 15.0 meters.

Avian Analysis

Bird Species Diversity and Abundance—Bird species diversity (BSD) indices were computed. Figure 5 is a plot of the regression equation for these indices against age of stand. A highly significant fit of the data to this curve was obtained (P <.01). The regression analysis and plot of the regression equation clearly show a projected rise in BSD in the early stages after cutting from an estimated value of 2.02 at year 0 to a peak of 2.90 at about year 23 after which it declines.

The 11 year old stand was found to have the highest BSD, 2.87 with 20 species. A relative abundance statistic (Conner and Adkisson, 1975) computed for each stand (Table 2) shows the most abundant species in the stand to be the chestnut-sided warbler (*Dendroica pennsylvanica*), rose-breasted grosbeak (*Pheucticus ludovicianus*) and veery (*Catharus fuscescens*).

The 17 year old stand had the second highest BSD, 2.76 with 16 species. The most abundant species in this stand were the ovenbird (*Seiurus aurocapillus*), veery and least flycatcher (*Empidonax minimus*).

The 35 year old stand had the third highest BSD, 2.59 with 16 species. The most abundant species in this stand were the least flycatcher, red-eyed vireo (*Vireo olivaceus*), ovenbird and veery. The least flycatcher had the highest abundance in this stand.

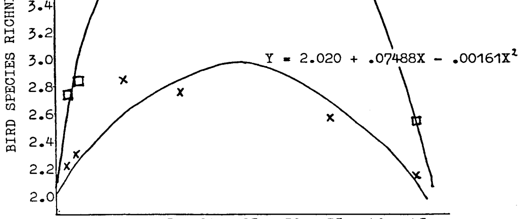

Fig. 5. Plot of regression equations and data for bird species diversity (X) and richness (□).

The 5 year old stand had the fourth highest BSD, 2.32 with 17 species. The most abundant species in this stand were the chestnut-sided warbler, ovenbird, Nashville warbler (*Vermivora ruficapilla*) and rufous-sided towhee (*Pipilo erythrophthalmus*).

The 3 year old stand had the fifth highest BSD 2.20 with 16 species. The most abundant species in the stand were the chestnut-sided warbler, mourning warbler (*Oporornis philadelphia*) and rufous-sided towhee.

The 45 year old stand had the lowest BSD, 2.16 with 13 species. The red-eyed vireo had the highest abundance in this stand.

Bird Species Richness—The richness component (number of species) of bird species diversity was computed for each of the stands. Figure 5 is a plot of the regression equation of species richness against age of stand. A significant fit of the data to this curve was obtained (P<.02). The regression analysis and the plot of the regression curve clearly show a projected increase in species richness in the early stages after cutting from a value estimated at 2.15 at year 0 to a peak value of 4.61 at year 24 after which it declines.

Bird Species Evenness—The evenness component (number of individuals of each species) of bird species diversity was computed for each stand. A regression analysis of species evenness values showed no significant difference with age of stand (P<0.3).

Discussion

Trends in BSD With Age of Stand—This study demonstrates an almost complete change in the avian fauna over a 45 year period following clearcutting. These results agree with the findings of Conner and Adkisson (1975). A trend in BSD was observed in which diversity was low in the 3 year old stand, high in the 11 year old stand and low in the 45 year old stand. Data collected in 1976 suggests that the BSD in the 3 year old stand was initially lower and BSD in the 45 year old stand was nearly the same as in 1977. There was no difference in the evenness component of BSD with respect to age of stand. Tramer's (1969) work on the components of Shannon's Formula of diversity lends support to this observation in that he found breeding bird communities to be relatively constant with respect to the evenness component of species diversity. Alternatively, Adams, et al., (1976) and Webb, et al., (1977) found evenness to be greatest in the early stages after clearcutting.

The richness component of the BSD index

TABLE 2. Relative abundance of bird species in the six study areas.

Species	*3 yr.*	*5 yr.*	*11 yr.*	*17 yr.*	*35 yr.*	*45 yr.*
Tree swallow	.033					
House wren	.067					
Gray catbird	.067					
Brown thrasher	.033	.088				
Mourning warbler	.100		.064			
Indigo bunting	.067	.029	.032			
American goldfinch	.033					
Rufous-sided towhee	.100	.088	.064	.073		
Field sparrow	.033					
Chestnut-sided warbler	.200	.147	.096	.037	.035	
Golden-winged warbler	.100	.058	.032			
Northern flicker	.033					
Eastern kingbird	.033					
Eastern phoebe	.033					
Brown-headed cowbird	.033	.029	.032	.037	.035	.038
Song sparrow	.033					
R.-t. hummingbird		.029				
Blue jay		.058	.032	.037	.035	.038
Veery		.058	.096	.111	.107	.153
Red-eyed vireo		.058	.032	.111	.107	.192
Ovenbird		.088	.064	.074	.107	.115
Rose-breasted grosbeak		.029	.096	.074	.071	.076
Nashville warbler		.088	.032			
Black and white warbler		.029	.032			
Canada warbler		.029				
American woodcock		.058				
Yellow-bellied sapsucker		.029			.035	
Downy woodpecker			.064			.038
Great crested flycatcher			.032	.037		.038
Least flycatcher			.064	.111	.178	.115
Eastern wood pewee			.032	.074	.071	.076
Black-capped chickadee			.032	.037		
American redstart			.032			
Scarlet tanager			.032	.037	.035	.038
American robin				.037	.035	
Wood thrush				.037		.038
Cedar waxwing				.074	.035	
Hairy woodpecker					.035	
Ruffed grouse					.035	
Black-throated green warbler						.038
TOTAL individuals	60	68	62	54	56	52
TOTAL species	16	17	20	17	16	13

in the present study increased to a maximum in the 11 year old stand and then decreased with continued age of stand. This trend is similar to that found for oak-hickory clearcuts by Ambrose (1975) and Conner and Adkisson (1975), although this trend was not observed by Conner, et al. (1979) for pine-oak clearcuts. This evidence suggests that the kind of trend which might be expected for the various components of the breeding bird species diversity index for any given region might be dependent on stand type.

BSD In Relation To Vegetation Structure—The trend in BSD starting at a low diversity, increasing in the early stages after cutting and then decreasing again is not supported by a corresponding trend, either positive or negative, in tree or shrub species diversity (Fig. 2). Several researchers have suggested a close correlation between breeding bird diversity and foliage structural diversity. Although no measurement of foliage height diversity was made in this study, it was observed during vegetation sampling that the 11 year old stand appeared to be more complex, in the development of vegetation layers, than any of the other stands (Fig. 4). Tramer (1969) suggested that it is possible that the foliage height diversity determines the number of niches (at least in the physical sense) and thus the number of species which can coexist within a given community. BSD appeared to be associated with vegetation structural diversity in the present study.

Milewski and Campbell (1976) suggest a correlation between floristic diversity and bird species diversity. However, Bond (1957) and MacArthur, et al., (1962) suggest that there is little or no dependence of bird species diversity on floristic diversity. The results of the present study tend to support the latter idea.

Clumping of vegetation or patchiness has been found to relate to faunal diversity (Wiens, 1974, Hooper, et al., 1975) and in some cases has been shown to be more important than foliage height diversity (MacArthur, et al., 1962). Horizontal heterogeneity (patchiness) of vegetation was not measured in the present study. However, patchiness was observed in the 3 year old stand. This patchiness was in the form of clumps of stems occurring at the site of old stumps of maple and oak where sprouting took place. In some cases these clumps consisted of around 25 to 75 stems. Patchiness of slash caused breaks in the vegetation, but did not seem to greatly affect the BSD of the 3 year old stand as indicated by its relatively low BSD index. It is possible that some of the other stands may have had greater, but less visible, patchiness in their vegetation which may have affected the BSD found on those stands.

In the 5 year old stand the aspen saplings began to separate from the shrub layer to form the beginnings of a distinct tree canopy (Fig. 4). Wilson (1974) suggests that in a series of increasing complexity of vegetational structure, the addition of trees in the series has a major impact on the addition of avian species. Karr and Roth (1971) express a similar concept when they state that the maximum rate of increase in avifauna diversity occurs between 100 and 150% cover when both shrub and tree layers are being added. It can be seen in Table 3 that the number of species (across the cline in age since clearcutting) begins to increase in the 5 year old stand. It should also be noted that in the 5 year old stand and moving towards the older stands the number of forest bird species increases rapidly, replacing species of open field and shrub habitats.

Conclusions and Summary

The data presented here clearly demonstrate a nearly complete change in the

TABLE 3. Bird species number in relation to stand size.

Age of Stand (years)	*Size of Stand (ha.)*	*Number of Species*
17	15	17
35	30	16
11	50	20
5	65	17
3	90	16
45	140	13

species composition of the breeding bird population in a northern hardwood forest following clearcutting. Predicted bird species diversity is initially reduced by clearcutting and then begins to increase until the stand reaches 22 years of age after which it declines. While the plot of the data suggests that the numbers of species decreases rapidly after the high value is passed at the stand age of 22 years, the actual situation would probably be close to that shown by Conner and Adkisson (1975) where the number of species levels off or increases as a climax condition is approached. Structural changes in the vegetation brought about by clearcutting and the subsequent successional stages are most important. The data also indicate that the shift back toward the original species composition occurs rather rapidly in the first 10-11 years following cutting after which the change is much slower.

It is clear from the present study that clearcutting increases bird species diversity and increases density of individuals. An important loss due to clearcutting is the almost complete displacement of the original species population; however, this displacement is not a long time effect, since 85% of the species found in the control stand were reestablished in the 11 year old stand.

It appears that clearcutting in relatively young aspen-birch stands is not deleterious to avian diversity over the long term. In terms of management, cutting should be done to preserve sections of the original habitat in order to assure the maximum diversity of bird life in the area. Although forest fragmentation may not be a serious problem in northern Wisconsin because of the extensive forest canopy present, it may be a consideration in individual cases of clearcutting.

The size of the area being clearcut is a factor which must be a part of a management plan. The stands examined in the present study ranged in size from 15 to 140+ hectares. Conner, et al. (1979) has suggested a size limit of approximately 12-16 hectares which should be large enough to include most species of birds with the exception of those having large home range requirements. Data from the present study do not support a correlation between number of bird species and size of clearcut (Table 3). However, it should be remembered that these stands are not of equal age. Although these data do not suggest a size limit for clearcuts, it would seem apparent that a limit could be at some size equal to or less than the smallest stand in this study (15 ha.).

Acknowledgements

This study was supported in part by the Steenbock Fund of the Wisconsin Society for Ornithology and the University of Wisconsin-Green Bay Graduate School. I would like to thank Robert S. Cook, Keith L. White and D. M. Girard for reviewing earlier drafts of the manuscript. Also I would like to acknowledge D. Jowett and Christa Schwintzer for advice and technical assistance. The staff of the Wausaukee ranger station provided weather information and helped in locating clearcut stands. Amy Steffen and John Baum assisted with field work and manuscript formulation.

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RELATIVE NESTING SUCCESS OF YELLOW-HEADED AND RED-WINGED BLACKBIRDS

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Abstract

At Collins Marsh, Manitowoc Co., WI, Red-winged Blackbirds fledge significantly fewer young per nest and have a significantly higher rate of nest failure than Yellow-headed Blackbirds. As a result of interspecific territoriality Red-wings are prevented from breeding in areas they would otherwise use. Thus, competition for nesting habitat results in lowered reproductive rates among Red-wings. A major factor causing the lower reproductive rates is increased egg predation.

Previously Minock and Watson (1983) reported that Yellow-headed Blackbirds (*Xanthocephalus xanthocephalus*) and Red-winged Blackbirds (*Agelauis phoeniceus*) are interspecifically territorial at Collins Marsh, Manitowoc County, Wisconsin. This has also been found in western parts of North America (e.g., Orians and Willson 1964, Miller 1968), and in both regions it results in Yellow-heads using emergent vegetation over deeper, more open, water for nesting and Red-wings being forced to the periphery of the marsh. We found mean water depth of 37 cm beneath 25 Yellow-head nests and all nests were in cattails (*Typha* sp.), while 18 Redwing nests were over water of mean depth of 21cm and 12 were on land. Red-wing nests were placed in vegetation of at least 7 different species.

As pointed out by others, this means that Yellow-heads exclude Red-wings from their "optimal niche space" (Robertson, 1972). I was interested in whether specific detrimental effects of this displacement of Red-wings at Collins Marsh could be quantified in terms of influence of the Yellow-head presence on Red-wing nesting success. One way to do this would be to remove Yellow-heads from the marsh and then compare nesting success between Red-wings on the periphery and those in what was Yellow-head habitat. This was not feasible. A second approach would be to compare nesting success between Red-wings at Collins with those at another similar nearby marsh without Yellow-heads. I did not attempt this and do not know if an appropriate situation exists. A third approach is to compare nesting success between Yellow-heads and Red-wings at Collins. I did this in 1980. A problem with this procedure is that there is no guarantee Red-wings would fare the same as Yellow-heads if the former had access to the area used by the latter. Such results, however, may be suggestive.

Nest searches were conducted in the southwest corner of the marsh. The nesting data reported here were gathered on 12 visits to the marsh from 16 May to 25 June and 1 visit on 3 July. Return visits to nests reported on in this paper, with one exception as follows, were made until young fledged or failure occurred. One way to estimate nesting success is to determine the number of young fledged per active nest (at least one egg laid). Nestlings were considered to have fledged if they were alive the next to last time I checked the nest and were gone and would have been old enough to fledge by my last visit. In addition, three 8 day old nestlings in a Red-wing nest on my last visit to the marsh were considered to have fledged, but three later active Red-wing nests were not included in the data. The results (Table 1) show a fledging

Table 1. Fledging success per active nest of Red-Winged and Yellow-headed Blackbirds at Collins Marsh.

	No. of nests	*Young fledged*	*Young fledged per nest*
Yellow-heads	19	36	1.9
Red-wings	23	24	1.04
*p			<.032

*Mann-Whitney U Test, one-tailed.

rate in Yellow-heads nearly twice that found among Red-wings. In addition to the difference in number of young fledged per nest, 14 of 23 Red-wing nests fledged no young whereas only 5 of 19 Yellow-head nests were total failures. This difference is significant ($P < .05$, Chi-square).

The two species are capable of producing similar numbers of eggs per clutch (e.g., Orians 1980). Red-wings are generally thought to have greater nesting success within marshes than in upland situations (e.g., Case and Hewitt 1963, Robertson 1972) (However, see Dolbeer, 1976). Young (1963), in a study mainly concerned with age-specific egg and nestling mortality, also found lower nesting success among Red-wings than Yellow-heads at a marsh near Stoddard, WI. These facts, together with my data, strongly suggest that competition with Yellow-heads for breeding territories is reducing reproductive success of Red-wings at Collins Marsh.

Of the 14 failed Red-wing nests, 12 were cases where eggs disappeared. This occurred in 3 of the 5 failed Yellow-head nests. It is likely that parts of the marsh preferred by both species but obtained only by Yellow-heads are less susceptible to predation than areas used by Red-wings. In his study Young (1963) suggested one reason for lower egg and nestling mortality among Yellow-heads might be reduced predation because of "the generally deeper water at the nest site." Robertson (1972) found that predation was the most common cause of mortality to Red-wing eggs (and nestlings) in both marsh and upland habitat but that it was greater in uplands. The other 2 cases of nest failure among Red-wings at Collins were from drowning due to nest submersion from rising water on a flood plain, and failure of eggs to hatch in a deserted wind-tilted nest. The remaining two nest failures among Yellow-heads were due to desertion and/or starvation since dead young were found in the nests. I have not attempted to analyze causes of egg or nestling mortality in nests that were partially successful. The role of differences in food availability to each species was not studied.

Acknowledgements

Thanks to Ronald Barrett for reviewing the manuscript, to Daniel Olson of the Wisconsin Dept. of Natural Resources for approval of use of the marsh and to John R. Watson for telling me about Collins Marsh in the first place.

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BIRD BEHAVIOR IN RESPONSE TO THE WARMTH OF BLACKTOP ROADS

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Abstract

In summer small birds are commonly seen on the surface of blacktop roads, particularly when the air is cool (< about 25° C, 77° F). In this study I recorded the species and numbers of birds on the road as observed from a car on a specific 20.6 km route daily and at different times of day; I related these observations to concurrent temperatures of air, road surface, and surface temperatures of adjacent open and shaded habitats.

The mean road temperature in full sunlight was 6.7° C higher than air temperature in shade. The highest numbers of birds (75.6% of total) on the road occurred when road temperatures were 7-10° C above air temperature (road 26-34° and air 19-26° C). Since the lower critical temperatures (LCT) of thermoneutrality for many passerine birds is 22-23° C, the birds can conserve metabolic energy by utilizing the solar heat stored in the road surface during the several hours each day when the road is at or above LCT and the air is colder. Additional stationary observations of birds and the length of time each stayed on the road at different road temperatures showed a similar pattern. Responses to other factors including wetness (after rain), clouds and wind were also considered.

The wide availability of the warmer microenvironment of blacktop roads, and the behavioral adaptation of the birds using it, may conserve enough energy in the critical breeding season for species at the northern margin of their range to reproduce more successfully or even to extend their breeding range.

Roads represent one of man's commonest and most extensive intrusions into natural areas. Road beds surfaced with asphalt have the capacity to absorb and retain large quantities of solar heat. The stored heat is released during the late afternoon and evening hours. As sunset approaches, the angle of incidence of sunlight decreases; therefore the sun's effectiveness as a radiant energy source for avian behavioral thermoregulation also decreases. Due to its heat storage and release characteristics, the road surface continues to offer a thermal environment often well above known lower critical temperatures (LCT) of thermoneutrality for many passerine species until well past sunset. Thus, when air temperature is cool and direct solar energy is least available, birds may still conserve metabolic energy by using the thermally favorable environment provided by lightly-traveled asphalt-surfaced roads. To do so the birds must modify daily behavior patterns so that they are present on the road during periods when the road surface is above, and ambient temperatures below, the species' LCT.

The purpose of this study was two-fold: first, to determine the magnitude and extent of difference in temperature regimes of the blacktop road and that of several adjacent natural micro-environments, and secondly, to determine whether daily road-visiting patterns of a wild passerine population indicated a relationship to road surface temperatures which could be construed as a form of behavioral thermoregulation. In addition data were collected to determine the extent of influence of rain, wind, and other weather phenomena on road-visiting behavior of birds.

Methods

Description of Study Area

Marquette County, in central Wisconsin, is an area of sandy moraine, outwash and wetlands. Agricultural land use has declined, many of the original farms reverting to natural vegetation, thus creating successional stages which offer ideal habitat for many bird species. The study area included parts of Shields, Crystal Lake, Newton and Harris townships. Aerial photographs indicate the area is approximately ¼ cropland and abandoned fields, ¼ remnants of oak savanna (chiefly *Quercus ellipsoidalis* and *Q. alba,* Whitford and Whitford, 1971) or plantations of red and white pine *(Pinus resinosa* and *P. strobus)* and ½ open marshes and swamps of tamarack *(Larix larcina).*

Data Collection

Observations of birds on the road surface were recorded at least once daily from 30 May through 30 August, 1974 and 1975, from an auto traveling a standard 20.6 km route over local roads of typical asphalt-gravel composition at a steady speed of 56 km/hr (35 mph). Traffic on these roads ranged from 0 to 10 vehicles per hour, averaging approximately 5 per hour. Data records included the times of meeting oncoming vehicles and the times during which I knew vehicles ahead had disturbed the birds. Analysis was based only on those samples without known disturbance. In addition, seven hours of stationary observations recorded the lengths of time birds remained on the road at various road and air temperatures.

Bird observations were recorded as the number of birds, by species and in total, which were seen upon the road surface during each 10 minute sample period. Birds observed on the road were grouped into three classes: those with ruffled feathers, demonstrating Class I sunbathing (radiant energy absorbing) posture (Hauser 1957); those with feathers smoothed, erect posture and no visible activity; and those involved in visible searching activity which would indicate anting or feeding behavior. The latter group was omitted from data analysis to eliminate potential confusion between feeding behavior patterns and thermoregulatory behavior patterns. The first two groups were analyzed independently to separate birds actively absorbing radiant energy from those which appeared to be in a thermoneutral state where they had no need to actively absorb energy to augment metabolic heat production.

Temperatures were measured with laboratory-quality mercury bulb thermometers and a three-probe remote-sensing thermistor recording unit. Probe placement was as follows: a) on the ground in a medium-dense stand of herbaceous plants dominated by grasses; b) on the litter surface under 20 year old pines; and c) at a height of 1.2m in shade to measure ambient air temperature. Two thermometers, bulbs shaded, were placed on the road surface until the readings stabilized to measure surface temperature in shade and in sun. Temperatures of all sites were recorded immediately before and after each bird counting period. The wide temperature range which was sampled allowed the road to serve as its own control for the study by comparing bird observations during both optimal, i.e. above LCT, and sub-optimal road temperatures.

The road surface was classified as wet, dry or damp (having puddles of standing water on an otherwise dry surface). Weather conditions such as rain, percent cloud cover and wind speed were recorded to determine their possible influence on bird presence on the road.

Data Analysis

Significant differences in microenvironment temperatures were determined using a calculator programmed for the mean and standard deviation of hourly groups. 09:00-21:00, on a monthly basis for June, July and August, 1974 and 1975. Analysis of variance was calculated for all hourly groups.

Influence of various weather factors and temperatures on bird use of the road was determined by comparing the mean number of individuals observed during all 10-minute periods for each weather condition or temperature range. The average number of minutes birds remained on the road at various road surface temperatures was analyzed in a similar manner for stationary observations.

An *a priori* Chi-square test, using temperatures arbitrarily grouped by 5° C units, was used to establish whether distribution of individuals was influenced by road surface temperature.

Finally, it was necessary to separate the effects of time and temperature, two strongly interrelated factors, to determine which had the greater influence on bird presence on the road. This was done by deriving coefficients of determination for each factor.

The specific formula used to separate the influence of time and temperature was designed by Dr. Eugene Lange, then a biostatistician with the University of Wisconsin-Milwaukee, and is as follows (Lange, 1978, pers. communication):

$$Y_{ij}k = \underbrace{\beta_o + \beta_1 H_i + \beta_2 H_i 2 + \beta_3 H_i 3}_{①}$$

$$+ \underbrace{\beta_4 T_j + \beta_5 T_j 2 + \beta_6 T_j 3}_{②}$$

$$+ \underbrace{\beta_{1,4} H_i T_j + \beta_{1,5} H_i T_j 2 + \beta_{2,4} H_i 2 T_j}_{③} + J_{k(ij)}$$

where $Y_{ij}k$ = k^{th} observation of j^{th} temperature and i^{th} time period

H_i = i^{th} time period of the day

T_j = j^{th} temperature

β_o = constant

$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6, (\beta_{1,4}), (\beta_{1,5}), (\beta_{2,4})$ = partial correlation coefficients

and where

1 produces the effect of time independent of temperature

2 produces the effect of temperature independent of time

3 produces the combined effect of time interacting with temperature.

The equation made it possible to use a regression analysis where hitherto this had not been possible due to the curvilinear relationships of temperature and activity. Regression analysis followed the form:

I Y = β_o = ①

II Y = β_o = ②

III Y = β_o = ③

IV Y = β_o = ① + ②

V Y = β_o = ① + ③

VI Y = β_o = ② + ③

VII Y = β_o = ① + ② + ③

Results and Discussion

The most commonly observed species were the Vesper Sparrow *(Pooecetes gramineus),* American Robin *(Turdus migratorius),* House Sparrow *(Passer domesticus),* and the Mourning Dove *(Zenaidura macroura).* In all, 2102 birds of 36 species were observed on the road surface.

Laboratory studies indicate that House Sparrow daily activity is energetically most efficient at an ambient temperature of 22° C (Kontogiannis 1968, Kendeigh 1969). Vesper Sparrows were found to have a LCT of 22.5° C, White-crowned Sparrows *(Zonotrichia leucophrays)* 23° C (Yarbrough 1971, King 1964). The metabolic rate of Red-winged Blackbirds *(Agelaius phoeniceus)* increases significantly at ambient temperatures below 25.6° C (Lewis and Dyer 1969); they concluded that this increased energy output was necessary to maintain proper body temperature, indicating that this is their LCT of thermoneutrality.

The road in full sunlight had a mean temperature for all observation periods 6.7° C higher than ambient air, 6.3° C higher than the ground layer in grassy cover, and 7.4° C higher than the litter surface under the pines. Analysis of variance for the various micro-

TABLE. 1. Temperature relationships of sites, 0900-2100 hours (CDT), May-August. Degrees of freedom and f-ratio are included for all samples seven or greater. Data from 1974 and 1975 records.

Month	Site	0900			1100			1400			Time 1500			1600			1800			1900			2000		
		N	*X* °C	*SD* °C	*N*	*X* °C	*SD* °C	*N*	*X* °C	*SD* °C	*N*	*X* °C	*SD* °C	*N*	*X* °C	*SD* °C	*N*	*X* °C	*SD* °C	*N*	*X* °C	*SD* °C	*N*	*X* °C	*SD* °C
June	Air*				15	21.84	4.65				14	26.48	3.26				5	18.11	4.62	19	20.73	4.43	62	17.57	4.10
	Hbg				2	22.22					1	27.20					5	20.66	4.28	19	20.82	4.01	49	16.92	3.42
	Llp				15	22.12	4.34				14	26.23	3.41				5	17.56	4.03	19	19.41	4.93	62	16.51	4.12
	Rds				15	30.03	4.04				14	38.43	5.10				5	24.67	4.62	19,	27.34	5.01	62	22.82	4.73
d.f., f-value					3,	54,	12.17				3,	51,	26.23							3	72,	9.12	3,	231	30.22
July	Air	3	18.14	0.85	26	26.00	3.63	4	25.00	3.21	27	28.66	3.05	8	25.69	4.22	12	27.82	3.13	35	24.33	3.20	72	22.98	2.94
	Hbg	3	17.59	0.85	2	32.80		4	33.92	6.10	4	30.28	0.96	8	27.08	3.42	12	27.92	1.47	35	23.97	2.94	72	22.43	2.94
	Llp	3	18.14	0.32	26	26.49	3.67	4	25.00	2.57	27	29.19	3.32	8	27.01	4.63	12	27.27	3.36	35	23.93	3.54	48	22.36	3.07
	Rds	3	27.78	1.47	26	34.67	5.16	4	36.39	4.17	27	34.21	5.62	8	36.46	5.03	12	37.36	3.89	35	31.38	4.31	72	28.31	3.09
d.f., f-value					2,	75,	34.18				2,	78,	14.86	3,	28,	10.41	3,	44,	28.30	3,	136,	37.17	2,	213,	84.46
Aug	Air	7	18.49	1.51	17`	25.16	2.96				13	28.59	3.76	9	24.40	3.83	20	21.22	3.08	22	20.76	2.31	24	19.93	2.86
	Hbg	7	18.73	1.05	1	31.11								9	23.64	2.94	20	21.47	3.96	22	20.22	2.34	14	18.13	1.93
	Llp	7	18.89	1.61	17	25.58	2.76				13	28.50	3.16	9	24.81	4.22	20	20.50	3.19	22	19.89	2.48	24	19.51	3.07
	Rds	7	25.47	1.99	17	34.34	3.36				13	39.60	5.05	9	34.69	4.40	20	28.92	3.48	22	26.86	2.39	24	25.58	3.12
d.f., f-value		3,	34,	34.07	2,	48,	33.52				2,	36,	21.56	3,	32,	12.25	3,	76,	19.42	3,	84,	32.53	2,	69,	20.30

*Column 1 indicates the sites, or microenvironments, of the compared temperatures: Air is ambient air temperature at 1.5 m height in shade; Hbg is the herb layer in open grassy cover; Llp is the litter surface in shade under pines; Rds is the road surface in the sun; Rsh is the road surface in the shade. The road surface readings were taken in places which had been in sun and shade respectively for at least one hour before the readings. All sites lay within a 20 yard radius and readings at each time were taken in rapid sequence. (See Methods).

environments sampled indicated that a significant difference of temperature existed between the road surface and all other areas sampled for all hourly sample sizes larger than seven ($p<0.01$, Table 1). Temperature differences between the naturally occurring areas studied were not found to be significant; however a larger data base would permit statistical differentiation of these areas (Johnson and Davies 1927).

Temperature records, grouped into hourly averages for each month, June-August, indicate that the road surface offered favorable temperatures for several hours after air and other microenvironmental temperatures had fallen below 22° C, the LCT of most of the species observed (King and Farner 1961). June records indicate that environs other than the road had mean temperatures above 22° C from 11:00-16:00 hours, while the road surface was 22° C or above from 07:00-20:00 hours daily (see Fig. 1). Road surface temperatures above 22° C were typical from 06:00-23:00 in July and from 08:00-21:00 in August, while temperatures of other environs sampled exceeded this level only from 11:00-20:00 and 10:00-17:00 respectively. Therefore, during these months, the road surface temperature was within or above the birds' thermoneutral range an average of seven hours more per day than were temperatures of ambient air or of other local habitats.

Of all non-sunbathing birds observed on the road, 75.5 percent were seen when the road temperatures were between 22 and 33° C; 12 percent were at temperatures above 33° and 12.5 percent at temperatures below 22° C. These temperature ranges represent 46, 30 and 24 percent of data collection periods respectively. Birds were observed in sun-bathing posture only occasionally at road surface temperatures of 20-26° C, but rapidly increased in number when road surface temperatures dropped below 20° C. Indeed, all non-feeding birds observed in the range of 10-16° C road temperature were exhibiting sunbathing behavior.

Stationary observations (Table 2) indicated that the greatest numbers of birds per hour (18) were observed at road surface temperatures of 30° C. This decreased to 1/hr at 19° C and 4/hr at 40° C. The mean length of time birds remained on the road per visit followed the same pattern as number of visits per hour, namely 5.4, 1.0 and 1.7 minutes per visit respectively.

In observations from the moving car,

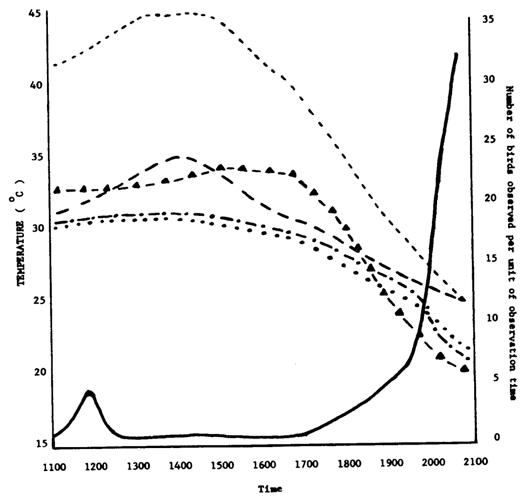

Fig. 1. Temperature curves of the five microenvironments for June 21, 1974, and total number of birds observed relative to time and temperature factors. Air --.-., Road in the sun ------, Road in the shade ——, Tall grass-....., Pine litter layer --▲-▲, Birds observed -- solid line.

Table 2. Time birds were present on road at various road surface temperatures. One hour of observation was conducted at each temperature level.

Temperature °C	*Birds Observed*	*Length of Time (minutes)** *Range*	*Mean*	*Standard Deviation*
40.0	4	1-3	1.75	0.96
35.0	7	1-4	2.14	1.21
32.5	13	2-9	4.69	2.39
30.0	18	1-11	5.39	2.57
26.5	9	1-7	4.44	2.23
23.0	2	1-2	1.50	0.71
19.5	1	NA	1.00	NA

*Times were recorded by 1-minute units with lengths of time over a minute recorded to the nearest minute.

mean numbers of birds per ten-minute period varied from 0.00-7.11 (range 0-26) when compared to specific road surface temperatures. Bird numbers were greatest when air temperature was 7-10° C below road surface temperature. Correspondingly, the mean number of birds observed on the road per ten-minute period was greatest within road surface and air temperature ranges of 26-34° and 19-26° C respectively.

The *a priori* Chi-square test of distribution of birds on the road surface relative to temperature indicated that distribution was not rectangular (99% confidence level, 6 d.f., 85.12). A similar test of bird distribution relative to time failed to show the relationship significantly non-rectangular. Rectangular distribution of an *a priori* Chi-square is a form of null hypothesis which assumes that one factor has no influence on another (Games and Klare 1967). Therefore, rectangular distribution, relative to temperature, would be expected if foraging or other behavior patterns were the primary reasons for birds being present on the road. Non-rectangular distribution relative to temperature indicates that the presence of birds was strongly related to temperature. Coefficients of determination were used to further isolate the effects of time of day from those of temperature via the formula given earlier. These indicated that temperature had nearly four times as great an influence on bird presence as did time of day, once the effects of the interaction of time and temperature were removed. The coefficient of determination derived for temperature was .1014 as opposed to .0270 for time of day. These figures represent only relative influence of the two factors and are not to be interpreted as correlation coefficients. However, they do support the hypothesis that bird presence was related to the temperature of the road-surface and not to temporal behavioral patterns.

General trends of influence for various weather factors and road surface conditions, based on the mean number of birds observed in each category, were as follows: 1) more birds were present when vegetation was damp from dew or rain than during dry conditions (14.7 vs 4.0 birds per 10 minute period, respectively); 2) scattered or broken cloud cover resulted in greater bird numbers observed than in clear or overcast conditions; 3) bird numbers steadily decreased (5.9 vs 2.6 birds per 10 minutes) as wind velocity increased from 0-19 km/hr; 4) bird numbers were greatest (10 per 10 minutes) when the road surface was wet and were lowest (4.4 per 10 minutes) when the road was dry.

As indicated above, damp vegetation resulted in nearly a four-fold increase in bird numbers observed, whereas numbers steadily decreased as wind strength increased. Explanation of these differences is relatively easy, i.e. wet feathers conduct heat more rapidly than dry and thus increase energy loss to the environment while the warmer, drier air at the road surface both reduces this heat loss and increases the rate of drying. Increasing wind speed also increases the rate of conducted heat loss from the birds which may partially or wholly negate the benefit of the warmer microenvironment. Both heat conductance and radiant energy flow are important to animals in terms of behavioral thermoregulatory processes and reduction of metabolic energy demands (Rosenberg 1974, Porter and Gates 1969).

Avian thermoregulatory behavior is highly flexible, e.g. feather ruffling permits change of insulation properties while sun-bathing behavior uses incident light orientation to control the rate of heat absorption (Lustick 1969). Great mobility allows birds to move to sheltered areas to reduce radiant and/or conductant heat loss or to select warm microenvironments which serve the same purpose. While many methods of behavioral thermoregulation exist, the ultimate goal of all the methods is the same, to achieve thermoneutrality with the environment. By definition, thermoneutrality is obtained when the minimum activity period metabolic rate of a resting animal is sufficient to offset heat loss to the environment and maintain proper body temperature. In other words, this is the temperature range in which the animal is energetically most efficient. Once thermoneutrality is obtained, radiant or conductant energy input cannot further reduce the metabolic rate of the organism; such inputs are of energetic importance only when the organism has an elevated metabolic rate in response to temperatures below the LCT of the species (Morton 1967). Thus radiant energy absorbing behavior would have significance primarily when road surface temperatures were below the species' LCT or when other weather factors increased energy loss rates.

Sunbathing birds were observed when road surface temperatures were near, or more commonly, well below the LCT of the species. Under these conditions, birds apparently utilized radiant energy absorption in combination with the favorable thermal environment of the road surface in the effort to attain thermoneutrality with the macroenvironment.

Birds observed at road temperatures above 26° C, and most birds at 20-26° C, were not sunbathing, they were simply resting on the road with no particular orientation to incident light. This would seem to indicate that these birds were in thermoequilibrium with the thermoneutral zone they were in. Bird numbers on the road were greatest when the road surface temperature was within, and air temperature below, the LCT of the species observed (Fig. 2). The presence of the birds on the road seems, therefore, to indicate not an energy-absorbing response but a behavioral pattern of perhaps equal importance, the selective use of thermally favorable microenvironments when ambient temperatures are suboptimal. Such behavior reduces heat loss to the environment and therefore aids the bird in achieving thermoneutrality and thus reducing energy demands. The potential energy saving to the individuals adopting this

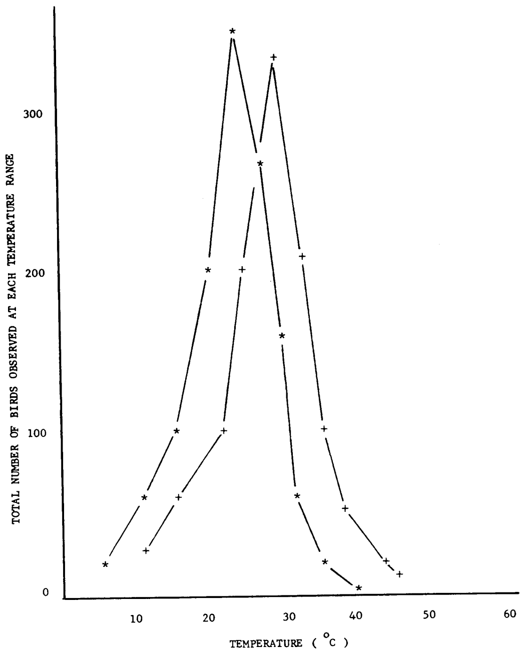

Fig. 2. Total number of birds observed on the road surface relative to both road surface and air temperatures. Air --*, Road surface -- +.
(Note that the greatest number of individuals were observed when the road surface temperature was within the birds' optimum temperature range and the air temperature was not.)

behavior pattern is a function of the amount of additional metabolic energy which would be required to maintain themselves at the lower ambient temperature for an equal length of time. Therefore, to determine the bioenergetic importance of this road usage, it would be necessary to know the extent to which individuals utilize this resource on a daily and seasonal basis. No such data exist at the present time.

On a theoretical level, widespread availability of lightly-traveled asphalt roads with their favorable thermal microenvironment offers a very real potential for northward range extension by avian species. The road surface in summer is above LCT of common passerine species an average of seven hours per day longer than ambient temperature. Sunbathing on the road when it is slightly below LCT (and air temperature well below), further extends the potential energy-conserving period. Obviously, feeding and other activities prevent full use of this potential resource. However, it has been shown that in cool climates avian species with altricial young often live near their limits of adult energy reserves during the breeding season (Yarbough 1970, Morton et al. 1973, Holmes 1976). Under these circumstances even moderate use of the roads' warm microclimate might reduce metabolic energy demands enough to improve breeding success and/or permit northward extension of breeding range by species displaying this behavior. The road surface average of 5-8° C above the ambient (climatic) temperatures is roughly equivalent to a 5-7° southward shift in latitude (480-800 km) (Goode 1975). Considering the magnitude of this microclimatic diurnal temperature difference, it would be surprising if bird species failed to respond by extending their ranges northward, especially since availability of suitable microclimates has been shown to be a major determinant of plant and animal distribution at the extremes of species ranges (Grimm 1937, Geiger 1965, Rosenburg 1974).

Summary

This study demonstrated that significant temperature differences existed between the natural habitats studied and the microenvironment of asphalt road surfaces. Road surface temperatures remained above 22° C, the LCT of many bird species, an average of seven hours per day longer than in the other adjacent microclimates.

Observations of 2102 birds of 36 species on the road surface were compared with time, temperature, and weather data to determine whether a pattern of usage existed. Analysis of these relationships indicated that road surface temperature was the major determinant of bird presence on the road.

Bird numbers were greatest when ambient air temperatures were below species' LCT and the road surface was above this temperature. All evidence indicates that these birds have modified normal diurnal behavior patterns to utilize selectively the thermoneutral temperature zone of the road surface. This occurred primarily during periods when birds would have had to elevate their metabolism to compensate for the decreasing environmental temperatures. Therefore, birds evidencing this behavior were able to reduce daily metabolic energy expenditures in proportion to the length of time they spent on the road each day.

Further studies are needed to determine quantative daily and seasonal energy savings derived by individuals using this behavior. Data derived from such studies would make it possible to assess more accurately the extent to which this altered behavior pattern may influence and alter breeding distribution of the species involved.

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THE BIOLOGY OF *CLASTOPTERA ARBORINA* BALL (HOMOPTERA: CERCOPIDAE) IN WISCONSIN

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Abstract

Clastoptera arborina Ball is a spittlebug (Homoptera: Cercopidae) that feeds on *Juniperus* and has been recorded recently in Wisconsin. It is univoltine, with the eggs hatching early in June, and the nymphs developing through five instars until early to mid July. Adults appear in early July and persist through early October. Nymphs spend most of their time feeding, primarily on the sap of the green succulent tissue. The fluid waste is formed into a frothy mass (spittle) in which the nymph lives. They usually stay within a few centimeters of their first feeding site while immature. The imaginal molt occurs outside the spittle. The adults are relatively freely living, capable of jumping and flying several meters or more. Adults also spend much time feeding. Mating is done in an end to end configuration and can last up to five hours. Eggs are deposited singly or in pairs under thin flaps of juniper bark. No parasitoids were collected, but the adults may fall prey to a variety of arthropod and vertebrate predators. No physical damage to the host was observed; however, large numbers of nymphs producing the spittle-like froth may be unsightly on ornamental plantings.

INTRODUCTION

Ornamental conifers, including the many varieties of juniper (*Juniperus* spp.) and white cedar (*Thuja*) are widely used in landscape plantings. Their range of color and shape, tolerance of dry conditions, and longevity make them ideal low maintenance plants for beautifying the many harsh environments created by human habitation and business. Insects that damage the aesthetic value of these plants therefore, can become as economically important as those that cause physical and physiological damage. Some species of spittlebugs (Homoptera: Cercopidae) are known to directly damage the host by causing yellowing and browning of the leaf tips, and by vectoring a wide variety of pathogenic organisms (Hamilton, 1983; Wilson and Dorsey, 1957). The spittle bug, *Clastoptera arborina* Ball utilizes *Juniperus* and perhaps *Thuja* as a host. The nymphal excreta of *C. arborina* is a white, frothy fluid deposited around the insect's body in the form of a spittle-like globule, and many such globules can be unattractive when viewed against the dark green foliage of most varieties. It also feeds on native *J. virginiana* L., which is an important part of the dry, rocky bluff and glade habitats common in Wisconsin. Therefore, both because of its possible economic significance, and because little is known about the general biology of the genus *Clastoptera,* we shall present our observations on the development, behavior, and ecology of *C. arborina.*

SYSTEMATIC POSITION, DISTRIBUTION, AND HOSTS

Clastoptera arborina (Homoptera: Cercopidae) was described by Ball (1927) as *C. obtusa* var. *arborina,* a color variety of what he considered to be a species based on structural information. The following year Doering (1928), realizing that an even more detailed structural examination was necessary to classify within the genus, published a revision in which the *arborina* variety was given species status. This scheme was maintained in her later keys of the Cercopidae (Doering, 1930, 1941). Hamilton (1978) found that she had misidentified her specimens of *C. arborina* in 1928 as *C. newporta* Doering, a new species, and had described a truly new species as "*C. arborina.*" Therefore, he synonymized *C. newporta* with *C. arborina,* and renamed the new species. This revision is maintained in his later key (Hamilton, 1983).

Ball (1927) originally recorded *C. arborina* from Muscatine, Iowa. Doering (1928) recorded collections (as *C. newporta*) from Connecticut, Lakehurst, NJ; Lake George, NY; and Newport, RI. Hamilton (1983) described its distribution from southern Ontario, south to N. Carolina and west to Iowa.

The type specimens were collected from "white cedar," presumably *Thuja occidentalis* L., by Ball (1927). However, Hamilton (1978) was unable to confirm this, but collected many specimens from eastern red cedar, *Juniperus virginiana* L.

Investigational Studies

Ten specimens of the insect collected in 1981 by H.C.C. were identified as *Clastoptera arborina* by J. P. Kramer of the Beltsville Agricultural Research Center, USDA, Beltsville, MD. This series and additional collections from 1983 and 1984 are kept in the research collection of the University of Wisconsin-Madison, Department of Entomology. *C arborina* was first recorded in Wisconsin from a *J. virginiana* planting in the southwest section of Madison, WI, where this study was subsequently undertaken on populations of *C. arborina* in: a residential area, the Odana Hills Golf Course, and two areas in the University of Wisconsin-Madison Arboretum: the Longenecker Horticultural Gardens, and the Juniper Knolls.

Materials and Methods

Number of Instars:

Dyar's law, that a dimension of a sclerotized structure should increase by a constant ratio between instars, was used to determine the number of instars of *C. arborina.* Every two days at least 10 spittle masses were collected from the field and taken to the laboratory. The nymphs were removed from the spittle singly and partially dried on ground glass using cross pins for manipulation. The greatest width of the head was measured under a stereo microscope at approximately 54X with a calibrated ocular micrometer. The daily sample size was not constant because some spittle masses contained more than one nymph, and all available nymphs were measured to ensure an adequate number of each instar for further study.

To determine the size of each instar, the measurements were grouped according to instar and numbered consecutively within the group. A random sample of 30 was obtained by using the total data, or a random sample chosen with the aid of a random number table (Snedecor and Cochran, 1980). The data are primarily from 1983, except for the measurements of the first instar, and additions to the second and third instars to complete the sample.

Seasonal History:

Random samples of 20 spittle masses were obtained approximately every other day, beginning with the first sighting of spittle on May 6, 1984. Randomization was done by constructing a grid over the surface of a juniper bush. At every sampling, 20 coordinates were drawn from a random number table (Snedecor and Cochran, 1980), and the spittle mass nearest each coordinate was removed from the bush. From head capsule size or general morphology, all nymphs were classified according to instar, and the frequency distribution (% of each instar) was recorded for each sampling day. When adults were found, the procedure was modified by counting either the fifth instar exuvia, patches of meconia, or both, if present, as an adult. Actual adult insects were not counted. This interpretation proved unambiguous, as the exuvia and meconia persisted in place for several days.

Hosts:

The plantings of *Juniperus* spp. and *Thuja occidentalis* in the University of Wisconsin-Madison Arboretum provided a unique opportunity for the investigation of hosts of *C. arborina*. Within the Longenecker Horticultural Garden, the "Pinetum" collection contained 32 cultivars of *J. chinensis,* 9 cultivars and varieties of *J. communis,* 1 *J. rigida,* 3 cultivars of *J. sabina,* 1 cultivar of *J. scopulorum,* 1 cultivar of *J. squamata,* and 18 cultivars and varieties of *J. virginiana.* All of these were in a 5600 m^2 area on a south facing hillside. A neighboring area contained more cultivars of *Juniperus* spp. and a hedge of *T. occidentalis* in juxtaposition. The other area of importance was the Juniper Knolls, which included a large area of juniper canopy and its fringe of isolated and semi-isolated *Juniperus virginiana* trees. A stand of *T. occidentalis* was located 50 m to the east, and the two areas were separated by an extension of the prairie habitat.

When the *C. arborina* nymphs were beginning the fifth instar, all plantings in the above areas were searched extensively for spittle masses. Approximately one month after the appearance of adults, a second survey was conducted including these same areas and the plantings around the administration building. In this study, adults were collected by sweeping the foliage with an insect net.

To determine the part of the plant utilized, the spittle masses observed in the seasonal history survey were scored according to the part of the branch they occupied. The categories were: a) "Core," including the trunk, major branches, and minor branches covered with true, cambium-derived bark; b) "Dry Twig," or the smaller branches covered with dried scales; c) "Green Twig," or the photosynthetic twig composed of long scales, concrescent proximally with only the tip free; and d) "Foliage," which in most varieties takes the form of branchlets bearing small, closely appressed scales.

TABLE 1. Head capsule measurements for nymphal and adult stages. n, sample size; $\bar{x} \pm SD$, mean ± standard deviation; Ratio, nymphal instar/previous instar.

Instar	*n*	$\bar{x} \pm SD$	*Range*	*Ratio*
I	30	0.333 ± 0.011	0.32 - 0.36	
II	28	0.485 ± 0.021	0.45 - 0.52	1.45
III	30	0.695 ± 0.037	0.60 - 0.76	1.43
IV	30	1.038 ± 0.047	0.90 - 1.13	1.49
V	30	1.552 ± 0.080	1.35 - 1.70	1.50
Adult	30	1.841 ± 0.080	1.66 - 1.96	
male	15	1.809 ± 0.080	1.66 - 1.94	
female	15	1.872 ± 0.068	1.72 - 1.96	

RESULTS AND DISCUSSION

Number of Instars:

Head capsule measurements clearly differentiate five nymphal instars (Table 1). The growth ratios are reasonably constant, and generally agree with the 1.4 expected from Dyar's law. The ranges of the 5th instar and the adult measurements overlap, but the head capsule width is otherwise diagnostic for each instar. The adult and nymph are easily distinguished morphologically. There is a significant difference ($P < 0.05$) between the adult male and female measurements, and the increasing standard deviation with each instar (Table I), particularly in the case of the 5th instar, may be partially due to this sexual dimorphism. Unfortunately, a lack of preserved specimens prevented statistical testing of the immatures.

Descriptions of Stages and Instars:

Egg (fig. 1): The egg is elongate, oval, and 0.835 ± 0.057 mm (n = 16) long. In the fall it

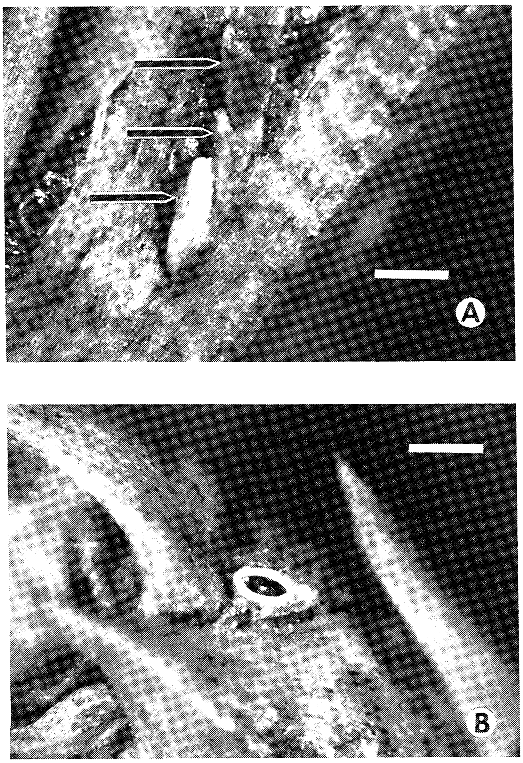

Fig. 1. *Clastoptera arborina* eggs *in situ:* A) during the fall (3 eggs, side view), and B) in the spring before hatching (1 egg, face view). Note the shiny black "egg burster" in B. Bar equals 0.5 mm.

is laterally flattened, with the broad side 0.362 ± 0.061 mm (n = 15) wide, and the narrow side 0.197 ± 0.037 mm (n = 12). It is deposited under a flap of the plant tissue with one end and most of a side (¼ to ½ of the circumference) remaining exposed. The exposed end is more pointed and narrower than the blunt inner end. A white patch of thickened chorion covers the central portion of the exposed area, but the peripheral chorion, like that covered by the bark or epidermis, is membranous and translucent to the yellow yolk. The white patch has a dark sagittal streak under the chorion. In the spring the egg swells, becoming round and splitting the chorion over the streak to expose a shiny black, oval "egg burster" (fig. 1B).

First Instar (fig. 2A,B): The head is yellow, round, and the width at the eyes is little more than the clypeus. The labium is surprisingly long compared to the total body length, and in dorsal view protrudes beyond the tip of the abdomen. Each eye consists of ten pigmented ommatidia. The antennae are short and two-segmented.

The thorax is yellow, cylindrical, narrower than the head, and dominated by the pronotum. The mesonotum has lateral triangular sclerotizations, and the metanotum is entirely membranous. The legs are translucent, long, and spider-like. The tarsi are two segmented.

The abdomen is initially yellow, contracted, only slightly wider than the thorax, and carried with the tip directed dorsally. After feeding it becomes distended (fig. 2B). There is a shallow groove parasagittally which marks the attachment of the dorsoventral muscles, and there are irregular transparencies in the integument permitting partial observation of the digestive and circulatory organs. Paired, brush-like structures of transparent filaments occur ventrally on segments 5 and 6 (fig. 3). These are shed with the exoskeleton at each molt. Similar structures are on segments 7 and 8 of *L. quadrangularis* and *Aphorophora parallela* Say (Guilbeau, 1914). Unlike the condition in *Tomaspis saccharina* Dist. (Kershaw, 1914), *Lepyronia quadrangularis* (Say) (Doering, 1922), and *Philaenus lineatus* (Sulc, 1910), the terga actually fuse in the ventral midline rather than merely touch or overlap (fig. 2G). The last tergum (9) is sclerotized, and its lateral edges curve ventrally and touch without fusing. Thus, the air canal enclosed by the sterna is a complete tube, closed anteriorly by a posteriorly directed triangular ridge of sternum 3, and open posteriorly at the margins of tergum 9. The remainder of the abdominal cuticle is unsclerotized.

Second Instar (fig. 2C): The second instar resembles the first, although it is larger. The eyes consist of 12-15 ommatidia on a widening of the head, and the antennae are short

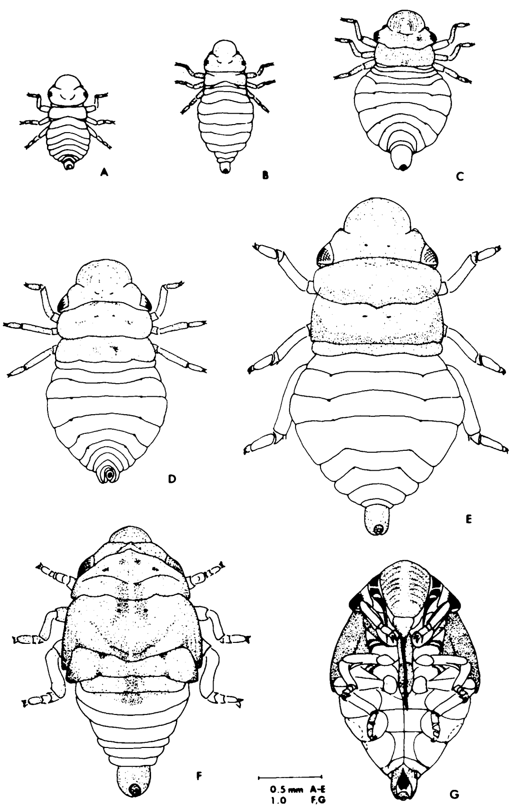

Fig. 2. Nymphal instars of *C. arborina.* A) newly emerged nymph; B) late first instar; C) second instar; D) third instar; E) fourth instar; F) fifth instar, dorsal view; G) fifth instar ventral view. Note the different scale for F and G.

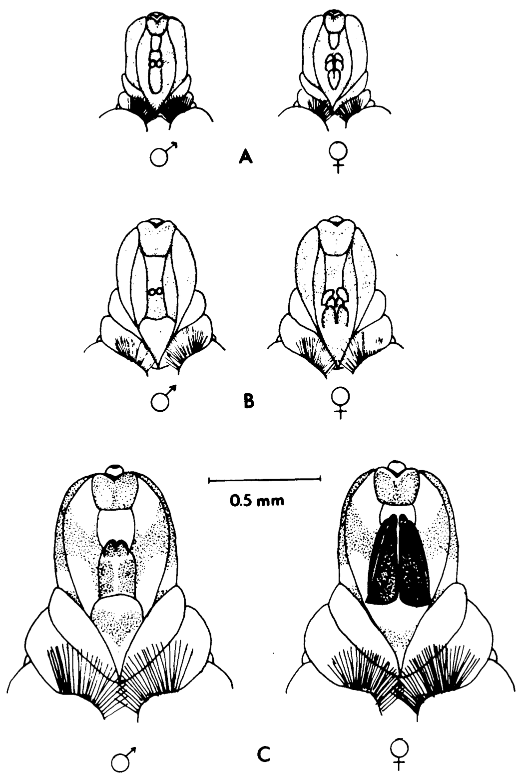

Fig. 3. Development of the genitalia. Ventral views of abdominal segments 5-9. Segment 6 is concealed by the enlarged fifth tergum and the curvature of the abdomen. The filaments mentioned in the text are shown as one clump. A) third instar; B) fourth instar; C) fifth instar.

and two-segmented. The thorax is more dorsoventrally flattened, and dominated by the prothorax. There is some sclerotization of the lateral meso- and metanota. The head, thorax and last abdominal tergum are usually olive green, and the remainder of the abdomen is yellow.

Third Instar (fig. 2D; 3A): The head is olive green and broad. The eyes are hemiconical and multifaceted, with the distal ommatidia darkly pigmented. Each antenna has two basal and one flagellar segment, and the ocelli first appear.

The thorax is dorsoventrally flattened, with the pro- and mesonota prominent. The legs and dorsal thorax are olive green. Wing pads become evident in this instar.

The abdomen is light yellow, although some internal organs may impart a greenish tinge. The ventrolateral areas of segments 4 and 5 may appear bright orange, due to a number of large pigmented cells in the body cavity of this region. Similar tissue was reported by Garman (1923) as the "spittle gland" of *C. obtusa* Say, and is also found in *L. quadrangularis* (Doering, 1922). The developing male and female genitalia become evident in the ninth sternal region (fig. 3A).

Fourth Instar (fig. 2E;3B): The fourth instar is generally similar in form and color to the third instar. The antennae have two basal segments, but flagella have a number of irregular, colored bands suggestive of segments. The sclerotized structures are olive green, although the shade is highly variable, and the head and thorax have dark patches. Anterior wing pads are prominent, and trachea can be seen entering them. Posterior wing pads are slightly developed. Each leg bears a fringe of apical tibial spurs.

Fifth Instar (fig. 2F,G;3C): Dorsally the head is crescent-shaped due to further broadening and shielding posteriorly by the pronotum. The color is olive green. Antennae are long and filamentous.

The thorax varies from dark green to grey or brown, and the darkening of the midline and wing areas makes it appear three-striped. The anterior wing pads are well developed, and exhibit some of the features of the adult tegmina. The posterior wing pads are less well developed and appear as lateral triangular thickenings. The meso- and metathoracic legs each bear a comb of apical spines, and all tarsi are three-segmented. Late in the stadium, black-tipped adult tibial spurs are visible under the nymphal cuticle.

The first abdominal segment is sclerotized and colored like the thorax. The second segment has a triangular, darkly pigmented patch, anteriorly as wide as the margin in dorsal view and narrowing to a point halfway along the midline. The remainder of the abdomen, except for the last tergum can be yellow or white depending on the individual. The genitalia are plainly visible on the last sternum; the valves of the ovipositor are jet black, and the claspers of the male are dark and sclerotized (fig. 3C).

Adult: Doering (1928) illustrated and described the adult in detail as *C. newporta.* We have found that the ovipositor's third valvulae are fused dorsally for one third their length and bear 68 ± 5.57 ($n = 25$) teeth along the dorsal margin between the fusion and the apex. Doering (1928) reported "about 82 teeth" for *C. arborina* while *C. doeringae* Hamilton has "81 to 90" and *C. media* Doering has "about 78." The structure of these valvulae is supposed to be of great comparative value for these closely related species. The red abdominal tissue is well developed, but not visible due to the pigmentation of the integument.

Seasonal History:

Clastoptera arborina is univoltine in Wisconsin, and overwinters in the egg stage. This is consistent with most other *Clastoptera* at this latitude on the continent, e.g. *C. hyperici* Gib. in Michigan (Hanna, 1969), but differs from the bivoltine *C. obtusa* of Connecticut (Garman, 1923).

The seasonal distribution of the different instars from the 1984 data (fig. 4) generally corresponds to the 1983 observations. Eggs with the "egg burster" were found in the third week of April, 1984. First instar nymphs were found on June 6, 1984, and an egg was observed hatching June 7, 1984. In both 1983 and 1984, adults began to appear in early July. Mating was first observed in mid July, and observations of mating continued into early October, when the last adults were collected (both years). Eggs were found in twigs caged with adults from July 27 to September 26, 1984. The seasonality of *C. hyperici* is similar to this, although Hanna (1969) does not give specific dates, and Garman's (1923) records for the species

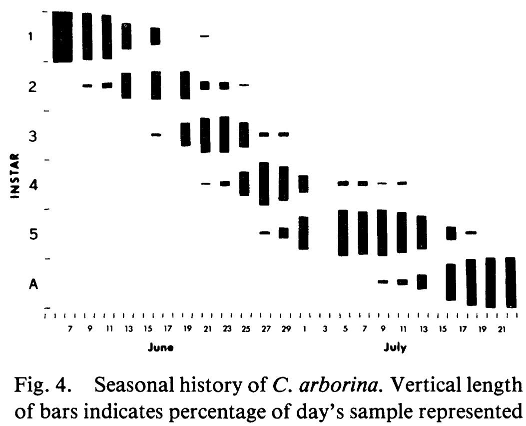

Fig. 4. Seasonal history of *C. arborina.* Vertical length of bars indicates percentage of day's sample represented by each instar. Eggs were not sampled.

mentioned above show a slightly contracted seasonality, with the first generation being advanced about 3 weeks.

Hosts:

Nymphs and/or adults of *C. arborina* were found on the following cultivars or varieties of *Juniperus* spp: *Juniperus chinensis* cultivars Ames, Blaauw, Columnaris Glauca, Fairview, Iowa, Keteleeri, Mission Spire, Mountbatten, Obelisk, Pfitzerana Aurea, Pfitzerana Glauca, Robusta Green, and Story; *Juniperus communis* cultivar Laxa; *Juniperus sabina* cultivars Fastigata and Von Ehren; and *Juniperus virginiana* from Juniper Knolls and cultivars Burkii, Canaertii, Globosa, Hillii, Hillspire, Pyramidalis, Skyrocket and variety *glauca.* A large collection of *J. horizontalis* was not examined for spittle masses, and no adults were collected; however, the low creeping growth of this species made the sweeping technique ineffective. *J. rigida, J. squamata,* and *J. scopulorum* supported neither nymphs nor adults, but together they made a small contribution to the total planted collection. Otherwise *C. arborina* is able to complete development on several species and varieties of *Juniperus.* Doering (1942) listed three other *Clastoptera* spp. collected from *Juniperus,* including *C. elongata* Doer., *C. juniperina* Ball, and *C. doeringae.*

Both the nymphs and adults of *C. arborina* prefer to feed on the green twigs of *Juniperus.* A Chi square (χ^2) test against the null hypothesis of equal utilization of the four areas was highly significant (Table II, $P < 0.05$). The green twig was the preferred feeding site, as this category made the greatest contribution to χ^2. Also only 5th instar nymphs and adults were found in the dry twig area, which can be attributed to the relocation of spittle masses toward the trunk as described below, and the free movement of the adults respectively.

TABLE 2: Parts of the juniper plant utilized for feeding by *Clastoptera arborina.*

Stage	*Core*	*Dry twig*	*Green twig*	*Foliage*	*Total*	χ^{2*}
Nymph	0	7	124	40	171	227.24
Adult	0	19	44	16	79	50.27

* 3 degrees of freedom.

Habits of the Nymphs:

Eclosion: The "egg burster" acts as a trap door at hatching, as its seam breaks cleanly through most of its circumference. The nymph is positioned in the egg with its head in the outer tip and its venter against the "egg burster." As it wriggles out of the chorion, its legs are worked free, and extended and flexed repeatedly until one catches an object such as a scale or twig. This action enables the nymph to pull itself into a standing position. The time from chorion rupture to complete eclosion is approximately 5-10 min. The nymph remains nearly motionless for about 20 min, after which it begins crawling about the foliage and twigs until it establishes the first feeding site.

Spittle Production: Doering (1922) briefly reviewed earlier accounts of bubble forming movements and related morphology in cercopid nymphs. In general, her description and conclusions accurately apply to the observations of *C. arborina* nymphs. As noted previously, four clusters of filaments are present near the opening of the air canal. Guilbeau (1914) reported that they are a secretion of the dermal glands of Batelli. His experimental and histological studies indicated that the secretion is necessary for the retention of bubbles in the excrement. We observed that the filaments usually come in contact with the newly formed bubbles as they are expressed from the air canal, so they may indeed contribute to this phenomenon.

Spittle production and maintenance was virtually continuous; however, the rhythmic movements of bubble making were frequently interrupted by short, ca 30 sec periods of breathing, where only a small "Y"-shaped vent (the space on either side of the anus and the adjoining median cleft between the tergal plates) was open for the passage of air into the air canal.

Activity: Nymphs are generally sedentary, although they are capable of rapid movement while immersed in the spittle. The principal activity is feeding, with the stylets inserted in the plant tissue. This necessarily renders the insect immobile, except for the abdomen, which is almost continually pumping back and forth. When the spittle is disturbed however, the nymph will withdraw its abdomen from the surface and its mouthparts from the plant, move to the opposite side of the twig, and take shelter in the axil of a scale if available. Usually the mass of froth is sufficient to obscure the presence and movements of a completely submerged nymph. The insect may remain submerged for at least a minute, although, unless disturbed again, it will protrude its abdomen and begin bubble making within a few seconds. Molting from one nymphal instar to another takes place inside the spittle mass, and one to several exuvia can be found floating in the fluid after the first instar.

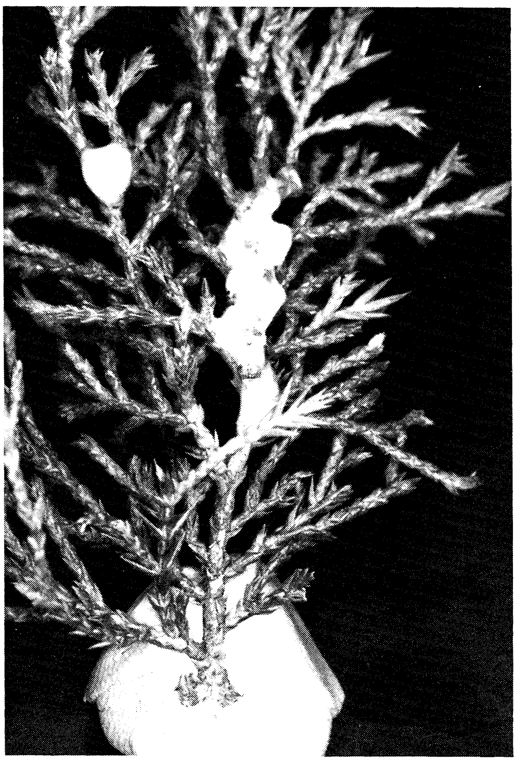

Fig. 5. Aggregation of eight fifth instar nymphs.

A nymph may abandon its original spittle mass and move to a new feeding site, usually on the same branch. Most abandoned spittle masses are a result of this relocation rather than nymphal death. This is based on observations of the number and location of spittle masses on marked twigs. The new masses were usually closer to the center of the plant. The number of exuvia in fifth instar spittle also suggests that this movement occurs during the third or fourth stadium. Wandering nymphs carry a film of spittle over their backs, and a cache of bubbles and fluid around their coxae. They crawl randomly, and intermittently probe the twig surface with their labellum until a new feeding site is found. If they contact another spittle mass however, they stop and enter it. This sometimes leads to aggregations of up to 8 nymphs in one continuous spittle mass (fig. 5). This is no doubt a common feature of the immature Cercopidae (Hamilton, 1983).

Natural Enemies: Nymphs may fall prey to a variety of arthropod predators, primarily of the order Hemiptera (Insecta) (Hamilton, 1983). Although we found no direct evidence of this, members of the family Reduviidae, Nabidae, Pentatomidae, and Miridae were found on juniper in association with *C. arborina*. One case of an ectoparasitic larva was observed, but it died soon after discovery, and no identification was made. It did bear resemblance to the illustrations of the drosophilid found on temperate *C. obtusa* (Baerg, 1920; Garman, 1923).

Impact: In spite of sometimes heavy feeding, we observed neither yellowing nor browning of the branchlet tips nor significant necrosis of the tissue around feeding sites. Thus, the physical or physiological damage caused by *C. arborina* is likely to be minimal for plants in unstressed environments.

Habits of Adults:

Imaginal Molt: The final molt occurs outside and usually towards the tip of the branch from the last spittle mass. Newly emerged adults are pale yellow without definite markings. As the thorax is freed from the nymphal skin, the wings are expanded, while being held in a vertical position. The legs and abdomen are then pulled free, and the genitalia are expanded to full size, and spread. After complete expansion, the wings are first lowered till horizontal and longitudinal to the body axis, and then slowly, ca 2 min, laid flat on the back. Emergence takes approximately 20 min. Failure to molt properly is a frequently observed mortality factor.

After molting, the adult may crawl a short distance before pausing for cuticular tanning. Development of the mottled white, tan, and black markings usually requries two or more hours, during which time the meconium is cast. The meconium is splattered on the foliage, and dries as a white plaster-like substance, resistant to rain, and persisting through the fall. After feeding, adult excreta is also splattered on the foliage as droplets of transparent fluid.

Locomotion: The adult *C. arborina* is essentially sedentary, spending much time feeding and mating, and it will usually tolerate the manipulation of foliage necessary for close observation. Short distance movement is by crawling, with the anterior four legs used in the typical insect gait, and the metathoracic (jumping) legs either held next to the abdomen in a "cocked" position, or used in an anterior-posterior pushing motion. Jumping is accomplished by an explosive extension of the hind legs, accompanied by a slightly audible popping noise. About 15 sec is required for cocking the legs after landing. Jumping is a frequent means of escape, but has also been observed in the froghopper's unmolested activity. In addition, after jumping, *C. arborina* may use its wings to alter its course, or extend its range several meters. Specimens of *Clastoptera* spp. were captured in the 20 m tower at Belle Plain, NJ (New Jersey Dept. Agr., 1927), which indicates a potential for long range dispersal of these insects, probably mediated by active flying.

Mating: During courtship the male rides on the back of the female, with the couple facing forward. The male and female genitalia are then coupled and mating begins. The pair may continue in this configuration, but usually the male lets loose and turns to face in the opposite direction. While joined, they do not feed, but can crawl in a push-pull fashion, and jump approximately 30 cm vertically. Copulation lasts from two to five hours.

Oviposition: Eggs are laid singly or in rows of 2 or 3 under a flap of either bark (most common, fig. 1), or the green twig or foliage epidermis. When in the latter succulent tissue, a brown necrotic area forms around the egg. The long axis is usually at a 20° to 50° angle with the long axis of the twig, or when laid in the axis of a branch and twig, its direction is nearly perpendicular to the plane of the branch and twig. The egg penetrates the bark and parenchyma, and often the phloem and outer xylem as well. In nature a twig rarely contains more than two oviposition sites.

Fecundity: Ten females dissected between July 25 and August 20, 1984 contained from 6 to 11 ovarioles in each ovary (median = 8). Mature oocytes (length = 0.773 ± 0.053 mm, n = 28 from 4 females) were present in the ovarioles and lateral oviducts beginning July 25, but some specimens contained only developing oocytes. From late July to early October all specimens contained one or more mature oocytes, and mating was observed throughout the interval. Unfortunately, adults did not survive more than a week when caged on juniper, so no estimate of total fecundity was possible.

Predation: Adults are probably more susceptible to predation than nymphs, although the small size and cryptic coloration of the former when viewed against the dry twig may provide some protection. In the laboratory they have been preyed upon by a toad, and a variety of arthropod predators including *Zelus socius* Uhler (Hemiptera: Reduviidae), *Phymata pennsylvanica* Handlirsch (Hemiptera: Phymatidae) and *Misumenops asperatus* (Hentz) (Arachnida: Araneae: Thomisidae), all collected from juniper. The froghoppers were captured by the predators only while moving about between feeding periods, presumably because their motion increased their visibility. Also they could frequently escape even after capture by using their explosive jump.

Acknowledgements

This research was supported by the College of Agricultural and Life Sciences, University of Wisconsin-Madison, and by research funds from The Wisconsin Department of Natural Resources through the School of Natural Resources, University of Wisconsin-Madison. We wish to express our sincere gratitude to John Haanstad for the photographic assistance, to Steven Krauth for the taxonomic assistance, to Dr. E. Hasselkus for maps and planting records of the Arboretum collection, and to the staff at the Arboretum for their cooperation.

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FEEDING SITE AND SPITTLE OF *CLASTOPTERA ARBORINA* BALL (HOMOPTERA: CERCOPIDAE)

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Abstract

Feeding punctures of *Clastoptera arborina* Ball stained bright red with safranin 0 dye in cross sections of juniper twigs. The punctures were primarily intracellular, passed through all tissue layers, and ended in the outer layers of xylem tracheids. Xylem feeding is consistent with this and other aspects of *C. arborina*'s biology, and with the habits of other cercopids. Most feeding sites were established midway between the resin canal and the scale edge, and a disproportionate number entered through the stomata. The stylet sheath bore diameter increased with age, and matched the maxillary stylet diameter. The mandibular stylets do not penetrate beyond the outer mesenchyme and/or epidermis.

In the field, spittle is a white frothy mass, but this becomes more fluid in later instars. Many kinds of insects are found in spittle masses, but these are probably accidental entrapments, and not indicative of natural enemies. Under 100% humidity, the spittle production rate of a fifth instar nymph is 109.6 mg/day.

Introduction

Juniperus virginiana L., the host plant of *Clastoptera arborina* Ball, usually grows in the well drained soil of limestone outcroppings, bluffs, and glades. These more arid environments present special problems of water retention for developing insects, especially during the cuticle tanning period immediately following ecdysis. Spittle insects are well adapted for coping with these problems, as they are able to utilize the plant's own sap to create a virtually aquatic microhabitat in a semiarid environment. The following study establishes the source and acquisition of nutrients and water for *C. arborina,* and describes the spittle and its rate of production.

Materials and Methods

1. Feeding Site Description

Twigs with spittle masses were removed from the plant and trimmed as close as possible to the feeding nymph. The nymph was usually removed from the twig before the twig sample was fixed in formalin, acetic acid, and 50% ethanol (18:1:1) for one or more days. The specimens were dehydrated in an ethanol series with 2 changes of 100% ethanol, cleared in xylene, and infiltrated and embedded in Paraplast.

Young juniper twigs consist of a fibrous xylem core surrounded by phloem and mesenchyme. The difference in hardness between the former and the latter two often resulted in the fracture of the vascular cambium during sectioning. This artifact was eliminated in later work by trimming one end of the Paraplast block down to the specimen and soaking the block in water for one or more weeks. The embedded specimens were then mounted on wood blocks and sectioned at 10μm. The resulting ribbon of serial sections was mounted on glass slides, stained with safranin 0 and fast green according to Johansan (1940), and covered with a cover slip. Measurements were made with a calibrated ocular micrometer.

2. Rate of Spittle Production

A humidity chamber was constructed of a 25 x 25 cm square polyethylene sheet. A hole approximating the mouth aperture of a polyethylene funnel (about 5.5 cm in diameter) was cut in the center, and the funnel taped in place, being fastened around its entire circumference. Two opposing edges were taped together to form a cylinder, with the funnel nozzle directed outward.

The host plant was a small, potted *J. virginiana* kept in an incubator under a photoperiod of 18 hours light and 6 hours dark. A trial began by placing a fifth instar nymph on an appropriate section of twig in the humidity chamber with the funnel directly below the nymph. The chamber was closed tightly around the twig proximal to the trunk with a twist tie, and similarly with the distal end, except that a moistened dental wick was included in the closure so that one end projected to the outside. The wick was kept moist throughout the trial. A preweighed vial was then fastened with tape or clay to the funnel nozzle. Similar units not containing nymphs served as zero controls. After three days the twig and apparatus were removed from the plant and examined. Only those setups with healthy nymphs remaining at the end were used for spittle production data. The vials and collected spittle were weighed on an analytical balance, and the volume estimated by drawing the contents into a 1 ml pipet graduated in 0.01 ml divisions.

Results and Discussion

1. Feeding Site Description

The histological study showed the feeding punctures of *C. arborina* in the tissues of its host, *Juniperus* spp., as indicated by the following evidence. Generally one feeding puncture was located in each twig specimen. Because *C. arborina* remains in the same spittle mass through several stadia however, two feeding punctures were occasionally found in the same specimen. Also, as nymphs sometimes withdraw their mouthparts and move when disturbed, they may move far enough away from the feeding site such that the sheath is excised during trimming. Thus, some samples inevitably contained no feeding sheaths, but in general the number found was as expected. When two nymphs were fixed with the twig specimens, their mouthparts were observed inserted in the feeding punctures after sectioning. Finally, no other type of damage was found consistently that would befit the mouthpart morphology and feeding behavior of *C. arborina*. The feeding punctures are very distinctive (Fig. 1).

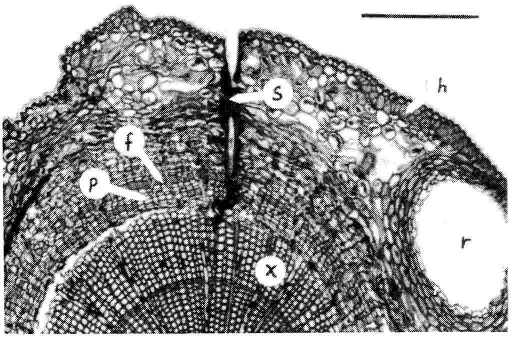

Fig. 1. Cross section of Juniper stem showing feeding sheath of fifth instar *Clastoptera arborina* Ball. *Abbr.* f - fiber cell band, h - hypodermis, p - phloem, r - resin canal, s - feeding sheath, x - xylem. *Bar* equals 0.25 mm.

As is the case with most Cicadoidea, the feeding puncture is primarily intracellular, and is lined with a sheath staining bright red with safranin 0 dye (Wiegert, 1964; Pollard, 1967; Cheung and Marshall, 1973). This is thought to be a salivary secretion, although some basophilic staining may be due to autolysis of the ruptured cells (Pollard, 1967). From observations on a cicadellid feeding through an artificial membrane, Bennett (1934) reported the secretion of a colorless fluid from the mouthparts that quicky coagulated to form a hyaline sheath around the stylets. This corresponds with the nature of the sheath reported here. Aphids produce a similar structure, but the feeding track is primarily intercellular (Balch, 1952).

The bore of the sheath is smooth, with the diameter increasing with the insect's age (see below), and the outer surface is irregular, being constricted by the plant cell walls, and expanding slightly into the cytoplasm, although not replacing it. The sheath continues through the air spaces between mesophyll cells, where its surface exhibits helical ridges, like twisted wrought iron.

The feeding tracks passed through many tissue types before ending in the xylem. A fibrous hypodermis was present near most feeding sites (Fig. 1), although it was absent directly below the stomata and other areas where punctures were predominantly located. Other tissues always encountered were the mesophyll, phloem sieve cells, ray parenchyma, and concentric bands of thick walled fiber cells. The stylets were usually worked *between* the latter. Except for the cells broken by the stylets, there was no other sign of damage to the tissues. Seventy-seven percent of all sheaths terminated in the xylem tracheids. These were generally in the outer layer of vessels, and usually only one cell showed signs of damage. The deepest tracks ended in the seventh layer of xylem from the outside. Sixteen percent ended in the xylem ray parenchyma, and here there was no evidence of xylem feeding. Pollard (1967) noted however, that in the mesophyll feeding cicadellid, *Eupteryx melissae* Curtis, maxillary extrusion was commonly far beyond the end of the sheath, in which instance, xylem actually may have been contacted. The thickness of our sections however, made this difficult to establish. In contrast to that of the phloem, xylem sap is a very dilute solution of inorganic ions, amino acids, and sugars. Thus xylem feeding is in keepng with the large amounts of fluid excreta produced by *C. arborina* nymphs and other spittlebugs, as large volumes of sap must be processed to extract the necessary nutrients.

The angle of stylet penetration was usually radial, although in 37% of the cases it was skewed from 20° to 45° from the radial. Also, the course of the stylets was generally straight, but in some specimens it curved slightly in either the transverse or longitudinal plane (29% of the cases), showed a slight elbow (14%), or curved in an "S" shape (2%). Branching was very infrequent, and often occurred at the level of the fiber cell bands. Usually only one branch was patent.

Clastoptera arborina nymphs and adults prefer the outer twigs and foliage branchlets of *Juniperus,* with the younger individuals predominantly on the more succulent tissue (Kuenzi and Coppel, 1985). Histological location of the actual punctures provides more specific circumstantial evidence characterizing feeding site choice and establishment. Examination of 42 sites revealed penetrations at virtually any point around the twig's circumference, including: between the resin canal and the scale edge (fig. 1) (88.0%), between scales (2.4%), at the edge of a scale (4.8%), into the resin canal (2.4%), and through the periderm (2.4%). Usually the point midway between the resin canal and the edge of the scale coincided with the lateral edge of an overlying scale (47.6% of the total), which is in keeping with the nymph's preference for sheltered locations. Where a first instar attempted penetration directly into a resin canal, sheath material was deposited a few microns inside the canal lumen, but there was no sign of continuation through to the other side. Interestingly, 54% of all penetrations were directly between guard cells of the stomata, and in two additional cases they were within one cell of a stoma. Brandes (1923) also noted that the stylets of *Aphis maidis* Fitch frequently entered the thin cuticle of the guard cells in corn, and Putman (1941) found over 10% of the stylets either entering the stomata, or passing between a guard cell and an adjacent epidermal cell in the mesophyll feeding cicadellid, *Typhlocyba pomaria* McAtee. As the stomata rarely occupy a large fraction of epidermal surface (7.8% of 218 mm^2 in

Juniperus), these observations may reflect a tendency of the spittlebugs either to use the vapor leaking through open stomata as a cue to initiate a feeding puncture, or simply to use the stoma as a path of low mechanical resistance.

The bore diameter, measured midway between the epidermis and xylem ranged from 4.2 to 25.2 μm (Table 1). A one way analysis of variance showed a highly significant instar effect ($P < 0.005$), but a least significant difference test failed to detect differences between successive instars at the 90% confidence level. A regression of the bore diameter against instar (the adult considered as the sixth instar) gave a linear trend with a slope of 2.7 μm ($P < 0.001$) and R^2 of 69.8%. It should be noted however, that the ranges and 95% confidence intervals of the first and second instar measurements overlapped completely (Table I). Excluding size, the stylet sheaths of the nymphs were all similar in morphology. The thickness of the sheath was from 2.9 to 11.6 μm in the second instar, and those of the other immature instars fell within this range. The sheaths of the adults and some fifth instar nymphs however, were very thin or not visible, and did not appear to traverse the air spaces as did those of the younger nymphs. The older individuals also damaged the xylem tracheids more, with several vessels being ruptured.

Pollard (1967) suggested that the mandibular stylets penetrated very shallowly, with the maxillae being extruded much farther. Thus the presence of such long sheaths in *C. arborina* feeding punctures may indicate extensive mandibular penetration into the plant tissue. As *C. arborina* feeds with its body aligned with the long axis of the stem, and the mandibular stylets are positioned lateral to the maxillae, the sheath bore diameter should correspond to either the maxillary or the combined stylet width. Transverse sections of second and fifth instar nymphs allowed direct measurement of the stylets. Allowing for some shrinkage of the plant tissue, the combined mouthparts were clearly too large to account for the bore diameter, but the maxillae were only slightly larger than the bore (Table I). Thus the mandibles of *C. arborina* are apparently inserted only a short distance, and in contrast to the mesophyll feeding *E. melissae,* sheath material is deposited along the entire length of the maxillary track.

Pollard (1967) also found that the depth of penetration increased with each instar in *E. melissae,* but this would not be expected in *C. arborina* due to the uniform thickness of mesophyll in the photosynthetic twigs. Indeed, a one way analysis of variance showed no difference in average penetration (all measurements were trigonometrically corrected for nonparallel sectioning) with an

TABLE 1. Measurements in micrometers of the sheath and mouthparts of *Clastoptera arborina* Ball. Numbers in parenthesis indicate sample size; $\bar{x} \pm$ SD, mean ± standard deviation; Rep., representative value.

Instar	SHEATH Bore Diameter ($\bar{x} \pm SD$)	Thickness (range)	Length ($\bar{x} \pm SD$)	MOUTHPARTS Maxillae (Rep.)	Max. and Mand. (Rep.)
I	6.13 ± 1.69 (6)		519 ± 64 (5)		
II	6.18 ± 1.18 (8)	2.9 – 11.6	489 ± 118 (8)	8.7	17.4
III	10.09 ± 3.65 (8)		482 ± 90 (8)		
IV	12.78 ± 5.16 (6)		533 ± 97 (6)		
V	15.75 ± 3.48 (5)	4.4 – 8.7	507 ± 99 (5)	29.5	49.2
Adult	19.43 ± 4.66 (4)		551 ± 61 (4)	29.5	49.2

overall mean of 513 μm and pooled standard deviation of 94.7 (30 degrees of freedom; $P > 0.25$). This is demonstrated by the values in Table I.

2. Description of Native Spittle

Early in the season the spittle produced by a first instar nymph is a small, white mass of tiny bubbles deposited in the fork of foliage branchlets or outer twigs. The size of this mass and of the bubbles increases with the growth of the insect, and the whitish appearance persists. Even in the first instar, the spittle often includes silken strands of unknown origin, plant hairs and other detritus, and the bodies of dead insects. All these components, with the addition of crystalline material, are found on the twig surface in abandoned spittle masses. In later instars, especially the fifth, the spittle becomes less frothy, and large globules of clear to yellowish, gelatinous spittle are found, sometimes with correspondingly colored patches of crust on the surface. Other than this, there is no change in the spittle of the pharate adult, as opposed to the condition of *Philaenus spumarius* (L.) and *Lepyronia quadrangularis* (Say), where, at this stage, the spittle is allowed to dry, and a cavity formed inside to accommodate the ecdysing insect (Doering, 1922; Weaver and King, 1954).

The following insects were found in various spittle masses in the summer of 1983: in the order Hemiptera: *Plagiognathus ilicis* Knight, *P. annulatus* v. *cuneatus* Knight (Miridae); in the Hymenoptera: *Euderomphale,* and *Omphale* (Eulophidae), *Aphanogmus* (Ceraphoronidae), *Copidosoma* (Encyrtidae), *Laelius pedatus* (Say) (Bethylidae), *Chelonus* (Braconidae), *Polynema* (Mymaridae), *Metaclisis, Platygaster* (Platygasteridae); in the Psocoptera: *Psocus* (Psocidae), and *Lachesilla pedicularis* (L.) (Pseudocaeciliidae); and a moribund unidentified dipterous larva. None of these have been reported as predators or parasitoids of cercopids, and we believe that their occurrence is either entirely accidental, or that they became trapped while utilizing the spittle as a water source.

3. Rate of Spittle Production

The spittle collected under near 100% humid conditions in the laboratory was slightly different from the spittle in the field. There were almost no bubbles in the mass around the insect, and usually none in the spittle collected in the vial. The spittle was very fluid and colorless, and never mucoid or of yellow tint. Most of it flowed from the insect into the vial, leaving only a film and a few bubbles covering the nymph and surrounding twig.

The liquid volume of spittle collected in the field was impossible to determine due to the difficulty in disassociating the entrapped bubbles (these bubbles were very persistent, even in alcohol-preserved spittle masses). Thus, without invoking more elaborate instrumentation, the density of native spittle could not be determined.

The density of spittle collected in the humidity chamber was 1.04 ± 0.02. The daily spittle production was 194.6 ± 73.7 mg ($n = 9$, range $101.6 - 291.3$) for the three days. For comparison, Horsfield (1978) found that the fifth instar of *P. spumarius* produced 1310 ± 80 mg/day under similar conditions, or 6.7 times that of *C. arborina. P. spumarius* is a larger animal feeding on herbaceous plants, and this may account for some of the discrepancy. Upon desiccation, a thin residue consisting of a mat of very fine interconnected fibers and small white crystals was deposited on the vial walls. None of the silken strands or detritus associated with the field spittle was observed. The residue thus probably corresponds to the filmy varnish seen coating the crystals and foreign inclusions in abandoned spittle masses in the field, and this soluble component, being concentrated by evaporation from the surface, could act as a thickening agent to increase the viscosity and structural integrity of the spittle mass. No further tests were performed, but studies have demonstrated the presence of amino acids (Wiegert, 1964; Hagley, 1969), sugars, and microorganisms (Wilson and Dorsey, 1957) in spittle of other cercopids.

Acknowledgements

This research was supported by the College of Agricultural and Life Sciences, University of Wisconsin-Madison, and by research funds from the Wisconsin Department of Natural Resources through the School of Natural Resources, University of Wisconsin-Madison. We express our sincere gratitude to John Haanstad for providing Figure 1, and to Steven Krauth for his taxonomic assistance.

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EFFECTS OF RECENT ECOSYSTEM CHANGES ON LAKE WINGRA BLUEGILLS

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Abstract

Since the International Biological Program funded studies in the late 1960's and early 1970's, Lake Wingra has undergone major floral and faunal changes. Among the most dramatic alterations are the disappearance of once-abundant yellow bass, the decline of European water milfoil beds, and the stocking of muskellunge on an almost yearly basis. This paper documents the timing of these changes and their impact on Lake Wingra bluegills. A winter 1984 sample shows a bluegill population with more rapid growth than at the last recorded sampling. The mean lengths for one, two, three, four, and five year old bluegills were 70, 102, 134, 154 and 165 mm respectively.

INTRODUCTION

The term "invisible present" was coined by Magnuson, et al., (1983) to describe the sum of ". . . . the events, processes, and changes occurring over decades . . . in the scientific study of lake ecology." Unfortunately, status quo surveys recording a lake's current conditions have traditionally been viewed as less exciting or intellectually challenging than other types of ecological research, and thus vital historical documentation remains sadly incomplete. Thus the recent concern over acid rain produced renewed interest in past environmental conditions, but records of lake chemistry, flora and faunal populations ranged from poor or spotty to nonexistent.

Ecological studies usually last one or two years and are generally not repeated, making long term changes difficult to assess. One exception is Lake Wingra's fish population, for it has been the subject of several studies during the past forty years. Serving as another link in the documentation of Lake Wingra's "invisible present," this paper describes recent changes in the lake's aquatic environment and especially its bluegill population.

Lake Wingra, a 140 hectare lake with a mean depth of three meters, is bordered on one side by the City of Madison and on the other by the University of Wisconsin Arboretum. Due to its proximity to the university, Lake Wingra has been regularly studied, and fifteen years ago its ecology and fish poplations were intensely researched in International Biological Program studies (Adams et al., 1972). Major work on Lake Wingra's fishes includes that by Pearse and Achtenberg (1918), Helm (1958), Baumann (1972), El Shamy (1976), and Churchill (1976). All these workers concentrated their studies on the abundant panfish: bluegills, yellow bass, perch, black crappies and white crappies. Baumann, et al., (1974) described the history of Lake Wingra's fish community up to 1973.

Bluegills, *Lepomis macrochirus,* numerically dominate the Lake Wingra fish community and they are also the most common fish in the angling catch. The average size is small (140-160 mm), and many fishermen consider them too small to bother catching or cleaning. However, a substantial size increase in bluegills taken through the ice has occurred in recent years. This increase occurred shortly after several dramatic changes in the Lake Wingra ecosystem, most notably the disappearance of the yellow bass, *Morone mississippiensis,* from the fish community, the decline of the aquatic macrophyte beds which formerly ringed the shoreline, and the stocking of muskellunge by the Wisconsin Department of Natural Resources.

Materials and Methods

In February and March of 1984 forty-eight bluegills were collected from the south end of Lake Wingra near the Aboretum's big spring. The fish were taken by angling from water less than one meter deep, using mousies (syrphid fly larvae), a small ice fishing jig, and two pound test line.

The bluegills were measured in total length to the nearest mm, and they were weighed to the nearest 0.01 gram. Scales were taken from below the lateral line in the area beneath the end of the pectoral fin.

Three scales from each fish were mounted between two glass slides, and the anterior scale radius and annular distances were measured to the nearest mm with a KEN-A-VISON model TECH-A scale projector which projected an image of the scales enlarged by 47 times. Average values from the three scales were used to back calculate lengths at each annulus. The best fit equation was $L = 51.53 + 0.78\ S$ ($r = 0.957$) where L = total body length (mm) and S = anterior scale radius ($\times 47$). Calculations used the Lee method as described by Carlander (1981).

Information on yellow bass disappearance came from my fishing records of Lake Wingra catches for the past fifteen years. This diary also provided information on the relative abundance of fish species in the winter catch from Lake Wingra.

Results

The high catches of yellow bass in 1969-72 (Figure 1) are misleading because I later learned to partially avoid them by fishing closer to shore. In spite of this, I believe that

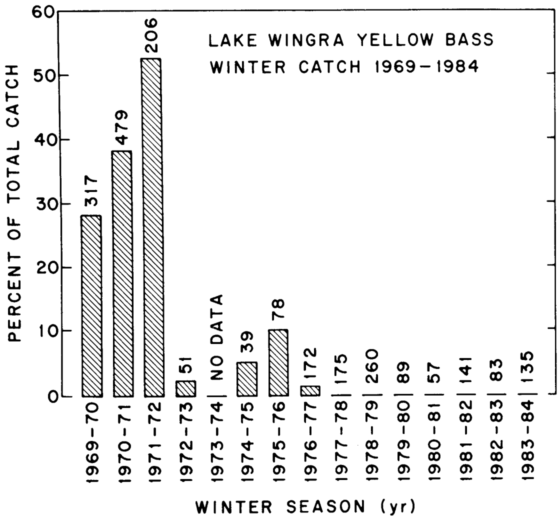

Fig. 1. The author's winter angling catch of yellow bass from Lake Wingra, 1969-1984, shown as a percentage of the total catch. The total number of fish caught is given above each column.

the trend shown in Figure 1 is real and that the yellow bass population had declined greatly before their ultimate disappearance. Yellow bass averaged 6.7% in Churchill's extensive sampling from 1972-74 (Churchill, 1976), and I caught a very similar percentage of yellow bass from 1972-75 (Figure 1). I caught my last yellow bass from Lake Wingra on January 10, 1977. I caught only two yellow bass that entire winter, indicating an extremely low population. I have not caught a yellow bass since then nor have I seen anyone catch a yellow bass; I therefore believe they are completely extirpated from Lake Wingra.

Prior to 1977, yellow bass made up 30% of my catch, bluegills 60%, perch 7%, and crappies (black and white combined) 2%. After 1977, no yellow bass were caught, bluegills made up 66% of the catch, perch 17%, and crappies 15%. Table 1 lists the actual catch data and taxonomic names for the various species.

The length-weight relationship for Lake Wingra bluegills in my 1984 sample was $\log W = -5.23 + 3.24 \log L$ ($r = 0.994$) where

TABLE 1. The number of fish of different species caught from Lake Wingra 1969-1984.

	Pre 1977	*Post 1977*
Yellow bass *(Morone mississippiensis)*	397	0
Bluegill *(Lepomis macrochirus)*	801	618
Pumpkinseed *(Lepomis gibbosus)*	10	7
Golden shiner *(Notemigonus crysoleucas)*	2	7
Perch *(Perca flavescens)*	98	162
Black crappie *(Pomoxis nigromaculatus)*	30	80
White crappie *(Pomoxis annularis)*	2	64
Largemouth bass *(Micropterus salmoides)*	2	0
Northern pike *(Esox lucius)*	0	1
Green sunfish *(Lepomis cyanellus)*	0	1
Total	1342	940
Number of fisherman hours	126.75	112.25
Fish/fisherman hour	10.59	8.37

W = weight in grams, L = total length in mm, and log = log to base 10.

Table 2 gives the back-calculated lengths for bluegills of each age class as well as a weighted average for the population. This 1984 sample shows that I, II, III, IV, and V annulus fish average 70, 102, 134, 154, and 165 mm total length respectively.

DISCUSSION

A major problem inherent in ecological field research is that variables cannot be carefully controlled nor accurately assessed. At least three major changes have occurred in Lake Wingra since the last published work on the bluegill population. These changes are a) the disappearance of yellow bass, b) the decline of the European water milfoil beds, and c) the stocking of muskellunge. The following discussion summarizes the history and possible causes of these changes, and attempts to assess their importance in sculpting the "invisible present" of Lake Wingra today.

A. What Happened To The Yellow Bass?

Ironically, yellow bass are now absent from both Lake Wingra, the site of the best Wisconsin study on yellow bass (Helm, 1964), and Lake Monona, the capture site of the world's angling record yellow bass—2 pounds, 2 ounces (Anonymous, 1976).

Figure 1 documents clearly the disappearance of yellow bass from Lake Wingra in 1977. At this same time yellow bass disappeared from nearby lakes Mendota and Monona, and populations of the closely related white bass dropped to very low levels. White bass did not occur in Lake Wingra in the 1970s; they had dropped to very low levels in Lake Monona in 1966 (Wright, 1968); and were declining in Lake Mendota in the early 1970s. Conjecture held that the yellow bass were eliminating the white bass by interbreeding with them. Supporting this idea, some Lake Mendota catches circa 1970 contained a few white bass, many yellow bass, and many fish which appeared to be hybrids between white bass and yellow bass. Therefore, the species disappearance in the winter of 1976-77 was primarily of yellow bass, since the white bass had declined earlier.

TABLE 2. Calculated lengths at each annulus and lengths at capture of bluegills from Lake Wingra, 1984.

Age	*Mean total length at capture (mm)*	*Number of fish*	*Estimated total length (mm) at time of annulus formation* I	*II*	*III*	*IV*	*V*
I	117	14	70				
II	140	11	70	103			
III	160	17	69	103	134		
IV	168	3	70	93	129	153	
V	180	3	72	107	136	154	165
		Weighted Average =	70	102	134	154	165

Yellow bass, white bass, and crappies are all known to exhibit extensive population fluctuations, the causes of which are unclear. While white bass have begun to reappear in Lakes Monona and Mendota as of 1984, yellow bass have not yet returned. The total extinction of yellow bass from lake Wingra was not sprayed. The simultaneous population fluctuation. Natural population control factors such as diseases and parasites seldom exterminate their hosts.

Local fishermen blamed the final yellow bass disappearance on spraying done to control aquatic macrophytes; however, Lake Lingra was not sprayed. The simultaneous disappearance of yellow bass in all three lakes implies a more widespread cause.

Baumann et al. (1983, p. 98) suggested that a more likely cause was the severe winter of 1976-77 when ice on area lakes froze to an extraordinary three foot thickness. Madison, Wisconsin, was at the northern edge of the yellow bass range, and moreover the yellow bass was likely a non-native species, introduced during the fish rescue operations in the 1930s and early 1940s (Noland, 1951). Baumann, et al., reasoned that this severe winter may simply have been too extreme for these more southern fish. Several facts argue against this idea. First, yellow bass inhabited Lake Wingra successfuly for approximately forty years in spite of some very cold winters. Second, Figure 1 shows a drop in the yellow bass populations beginning circa 1972, almost five years before their ultimate disapparance. This second fact especially argues for a long term cause, not the single event of one very cold winter.

Another more probable cause is the low background levels of agricultural chemicals which all our waters are currently receiving in rainfall and runoff. Even within the city of Madison one can go outside in the spring and smell the volatile chemicals being currently sprayed on the surrounding croplands. An atmosphere thick with herbicide droplets will dump its toxic load in every rainfall. The possible additive and synergistic effects of agricultural chemicals at low levels is unknown and unstudied.

The catch data in Table 1 indicate that yellow bass have been replaced in the fisherman's bag by perch and crappies. Catch per unit effort data support my observation that the perch and crappies do not currently approach the abundance shown by yellow bass in the early 1970s, and that bluegills are also less abundant now than in the early 1970s. Before 1977, my winter catch rate was 10.6 fish/fisherman-hour. After 1977, the catch fell to 8.4 fish/fisherman-hour, and the last three winters only 5.4 fish/fisherman-hour were caught. Comparison of crappie catches in the pre-1977 and post-1977 years is done with reservations. Use of more efficient equipment after 1977 resulted in a reduced crappie escape rate. Assuming this change in technique effects black and white crappies equally, the white crappie population appears to have increased since 1977.

B. The Decline of Water Milfoil

The second major change in Lake Wingra since the early 1970s is the dramatic decline in European water milfoil, *Myriophyllum spicatum*. After its introduction into the eastern United States from Europe, milfoil spread across the country, eventually dominating the aquatic macrophyte community in many lakes, including Lake Wingra and the other Madison lakes. According to Carpenter (1980), the decline of European water milfoil in Lake Wingra occurred during the summer of 1977. Many milfoil beds disappeared entirely, and the milfoil biomass in the remaining beds dropped to less than half its previous levels. Such patterns of changing abundance are typical for introduced species and are usually attributed to diseases and parasites catching up with the host plant. Carpenter was not able to attribute the decline of milfoil in Lake Wingra to any single observed factor. In 1984 Lake Wingra supported a more diverse aquatic macrophyte community, containing *Potamogeton, Ceratophyllum,* and *Vallisneria* in

TABLE 3. Muskie stocked in Lake Wingra 1972-84.

1984	700 Hybrid*
1983	No Stocking
1982	690 Hybrid 144 Muskellunge
1981	1000 Hybrid 15 Muskellunge
1980	1000 Hybrid 32 Muskellunge
1979	24 Muskellunge
1972-78	No Stocking

Hybrid = Northern Pike × Muskellunge.

*Anticipated stocking for 1984.

addition to *Myriophyllum*. Current macrophyte beds, however, are much less extensive than the water milfoil beds of the early 1970s which ringed Lake Wingra in a solid unbroken mass extending approximately 100 feet from shore.

C. Here Come The Muskies

The third major change in the Lake Wingra ecosystem is the stocking of predator species in the years following 1979. The rates of stocking are given in Table 3 (Klingbiel and Brynildson, 1984). A few pure muskellunge (*Esox masquinongy*) were stocked, but most fish were "tiger muskies," northern pike (*E. lucius*) X muskellunge hybrids. The great majority of stocked fish were fingerlings, juvenile fish about five inches long. Besides being highly prized sport fish, muskies are major predators on small panfish. However, muskies are stocked primarily to promote sport fishing and only secondarily to control panfish populations. Fishery biologists currently feel that stocking predatory fish at any reasonable level has a negligible effect on panfish numbers (Klingbiel and Snow, 1962).

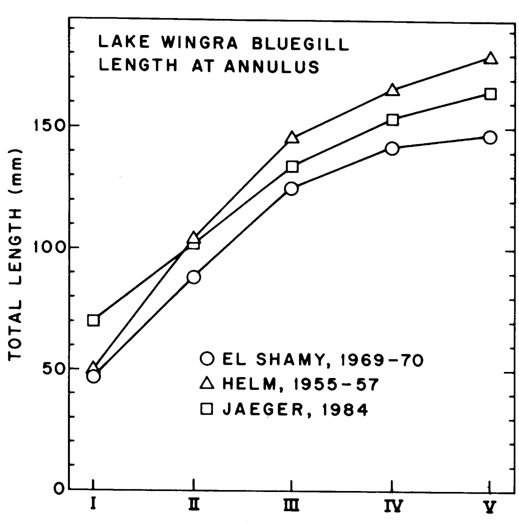

Fig. 2. The average calculated length at each annulus as determined by three recent studies of Lake Wingra bluegills.

Have Lake Wingra's panfish populations been measurably affected by the above ecosystem changes? Figure 2 compares the growth in length of Lake Wingra bluegills found in three separate studies. Adult bluegills in my 1984 sample grew at the same rate as adults in El Shamy's 1969-70 sample, but the fish are now 10 to 20 mm longer at each annulus. Churchill's 1972-73 sample calculated average lengths for bluegills which were almost identical to El Shamy's. Notice that Helm in 1955-57 found the same growth in the first year as El Shamy, but afterwards Helm's bluegills grew faster, and his curve gradually separated from El Shamy's. My more recent data show a major increase in the growth of young bluegills during the first year of life. This first-year increase in growth requires a cause which effects young of the year bluegills more strongly than adults.

My length-weight relationship ($\log W = -5.23 + 3.24 \log L$) supports the contention that bluegills are growing better now. El Shamy (1976) reported a length-weight relationship of $\log W = -3.788 + 2.57 \log L$ for Lake Wingra bluegills. Churchill (1976) reports a length-weight relationship of $\log W = -4.8904 + 3.062 \log L$ for bluegills caught in 1972-73. Churchill's results indicate that only three years after El Shamy's

1969-70 sampling, the bluegill length-weight relationship was already changing toward that which we see now. In fact, my length-weight relationship for Lake Wingra bluegills today is much closer to that of El Shamy's for Lake Mendota ($\log W = -4.99 + 3.21 \log L$), where bluegills consistently have grown much larger than in Lake Wingra. Simply stated, Lake Wingra bluegills of a given length are now considerably heavier than they were in 1969-70. This increase, effecting fish in all age classes, is the expected result in a population released from a major food competitor.

Thus we may now speculate with some confidence on how the three ecosystem changes discussed, acting alone or in combination, could produce the observed increases in bluegill growth. The disappearance of yellow bass, eliminating a potential food competitor, probably had the greatest impact on bluegill growth. The decline of the macrophyte beds may have allowed greater predation through a decrease in protective cover, again leaving the survivors with more food per fish. Or, the more open weed beds may simply make feeding easier for bluegills. Artificially elevating the predator population through muskie stocking would lower bluegill populations slightly, perhaps easing intraspecific competition. However, since relatively few muskies were introduced, predator stocking probably had the smallest effect on panfish populations.

It appears that competition between the remaining panfish species may be reduced by habitat selection and food preferences. While examination of stomach contents of perch and bluegills taken through the ice shows that both feed primarily on chironomids (lake fly larvae), interspecific competition is limited because perch are more pelagic and bluegills more littoral. Winter crappies eat small copepods not taken by bluegills or perch, and therefore appear not to compete with perch or bluegills for winter food. At the height of their abundance, yellow bass overlapped the habitats of all these species, especially the open water perch and crappies.

Summary

This study documented recent major species changes in the Lake Wingra ecosystem. Yellow bass, previously codominant with bluegills, vanished in 1977. The European water milfoil that once dominated the littoral zone has greatly declined. Muskellunge and northern pike-muskie hybrids were introduced. In response, the Lake Wingra bluegill population currently shows a greatly increased growth in the first year, and adult bluegills are longer at a given age and heavier at a given length than they were previously. Continuing documentation of the various aspects of Lake Wingra's changing "invisible present" are necessary to accurately assess and predict future ecosystem and fish population changes.

Acknowledgments

I would like to thank the Zoology Department for providing space and the scale projector, C. Hughes for illustrations, and D. Chandler for photography.

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ZOOPLANKTON DYNAMICS IN LAKE MENDOTA: ABUNDANCE AND BIOMASS OF THE METAZOOPLANKTON FROM 1976 TO 1980

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Abstract

Metazooplankton species composition, abundance, and biomass were followed from 1976 to 1980. Fairly similar annual cycles were found for the years studied. However, three types of differences were found: substitution of one species for another of the same genus, differences in the number of peaks and their time of appearance for certain species, and the maximum population abundances of most organisms. Results give insight into year-to-year variations and provide a data base to be compared with a similar study done almost one hundred years ago by E. A. Birge.

INTRODUCTION

The success of some long-term ecological studies (Bormann and Likens, 1979; Erlich, 1979) has recently focused attention on the need to have continuous records of data spanning as many years as possible. Studies of this sort address questions on a broader time scale than is possible with sporadic or seasonal studies. Thus, they allow distinctions to be made between seasonal changes and long-term trends, as well as to ascertain long term effects of human action or slowly changing environmental parameters upon ecosystems. Recognizing the importance of such studies, the National Science Foundation has established a new funding program termed Long Term Ecological Research (Callahan, 1984). The northern lakes of Wisconsin have been included as one of the eleven study sites funded by this program.

Lake Mendota, having been studied for almost a hundred years, offered a unique system for comparison of long and short term changes in its characteristics. By comparing data from modern studies with those from the existing literature, conclusions might be drawn about long-term changes in the lake. Stewart (1976) has made similar comparisons of data for oxygen concentrations and Secchi disk readings. The extensive studies carried out on the zooplankton of Lake Mendota by Birge (1897) offered a unique opportunity to contrast results gathered eighty years apart. Other studies on the zooplankton of the lake (see Frey, 1963, for a review) concentrated on particular aspects, such as vertical migration (Juday 1904), total biomass (Birge, 1923), sampling problems (Neess, 1949), patchiness and its causes (Ragotzkie and Bryson, 1953), feeding by fish (McNaught and Hasler (1961), or

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were concerned with taxonomy of different groups such as rotifers (Harring and Myers, 1921), cladocera and copepoda (Birge, 1918; Birge and Juday, 1908). However, no extensive study of zooplankton species density had been done since Birge's landmark paper (1897), and no quantitative studies on rotifers had been ever done.

Therefore, we carried out a study of Lake Mendota zooplankton, including species composition, abundance and biomass, from 1976 to 1980. The impact of feeding by zooplankton on the bacteria of the lake (Pedrós-Alió and Brock, 1983) and quantitative comparisons with Birge's data (Pedrós-Alió and Brock, 1985) have been published already. Detailed data for every species, sampling date, and depth can be found in Pedrós-Alió (1981). Here we describe the annual cycle of the zooplankton and discuss differences among the five years of the present study, as well as relations with their food sources, phytoplankton and bacteria. It is hoped that the results will become a useful data base from which to draw conclusions about long-term changes in a lake ecosystem.

Materials and Methods

Zooplankton sampling. Samples were taken at the deepest part of the lake (24.2 m) located towards the center of Lake Mendota. Three different techniques were used to collect zooplankton. The first one, vertical tows taken with a 20 cm diameter plankton net (mesh size 156 μm), was used during all years of the present study for two reasons: first, to provide an integrated picture of the zooplankton throughout the lake, and second, because this method is practically identical to that used by Birge (1897), which consisted of vertical tows taken with a 166 μm mesh size zooplankton net. In our study, the net was towed slowly from 23 m depth to the surface, thus sampling a water column of 723 1. Since not all the water in the column could pass through the net, the volume actually sampled would be somewhat smaller. Replicate subsamples, of 1 or 2 ml depending on the abundance of zooplankton in the sample, were removed with a Hansen-Stempel pipette and all the animals counted. The whole zooplankton sample was also examined to count all the individuals of *Leptodora kindtii,* since its relative scarcity and large size made counting of small volumes unreliable.

In addition to the vertical tows, two different techniques were used in 1979 and 1980, respectively, to provide information on vertical distribution of the zooplankton. During 1979, a fairly detailed discrete sampling technique was used. Samples were taken at a number of depths with a 5 1 Van Dorn bottle, and at least one liter from each depth was filtered on a Whatman GF/C glass fiber filter. The volume was reduced to a few milliliters and the vacuum disconnected. The filters were rinsed at least twice with filtered lake water and the wash water added to the concentrated sample. Examination of the rinsed filters showed a substantial amount of algae remaining on them, but no animals were ever found. This concentrate was then transferred into a gridded Petri dish and counted, using a dissecting microscope. Samples were also preserved in 4% formalin for later study. A simplified method, based on that of Likens and Gilbert (1970), was used during 1980. Discrete duplicate samples were again taken with Van Dorn bottles from several depths. Circular pieces of Nitex 64 net (64 μm mesh size) were fitted to a Sartorius filtering apparatus and volumes of water proportional to the lake volume at each depth interval were filtered through the Nitex net. During the period when the lake was totally mixed, two filtrations, representing a volume proportional to the whole lake were filtered. During the stratified period, two filtrations from the epilimnion and two from the hypolimnion were carried out separately (the thermocline was usually found between 10 and 12 m).

Thus, we had total population data from the vertical tows from 1976 to 1980, and ver-

TABLE 1. Lengths of the main zooplankton species in Lake Mendota for each sampling date during 1980. Average length in mm and, between parenthesis, ±95% confidence limits.

Date	Daphnia galeata	Diaphanosoma leuchtenbergianum	Chydorus sphaericus	*Calanoids*	*Cyclopoids*
Jan. 15	1.19 (.24)	—[a]	—	—	0.92 (.04)
Feb. 7	1.23[b]	—	—	—	—
Mar. 17	1.31 (.08)	—	—	1.25[b]	0.97 (.04)
Apr. 1	1.29[b]	—	—	—	—
Apr. 22	—	—	—	—	1.10 (.12)
May 12	—	—	0.34[b]	—	0.79 (.09)
June 2	1.20 (.18)	—	—	—	0.61 (.07)
June 11	1.22 (.13)	—	—	1.12 (.07)	0.66 (.04)
June 24	0.97 (.10)	—	—	0.70 (.09)	0.59 (.04)
July 1	1.41 (.16)	1.02 (2.9)	—	0.86 (.09)	0.86 (.07)
July 8	1.35[b]	0.74 (.37)	—	0.89 (.07)	0.88 (.07)
July 23	—	0.51 (.07)	0.18 (.01)	0.71 (.09)	0.54 (.08)
Aug. 12	—	0.73 (.13)	0.24 (.01)	0.96 (.06)	0.99 (.14)
Aug. 27	—	0.68 (.14)	0.24 (.01)	0.92 (.08)	0.73 (.09)
Sept. 8	0.91 (.36)	0.82 (.11)	0.24 (.02)	0.93 (.05)	0.67 (.09)
Sept. 22	1.63[b]	0.92 (.19)	0.26 (.01)	0.91 (.07)	0.69 (.08)
Sept. 29	1.56[b]	1.06 (.15)	0.27 (.01)	1.01 (.07)	0.84 (.09)
Oct. 6	1.48 (1.8)	0.97 (.10)	0.27 (.01)	0.93 (.07)	0.76 (.06)
Oct. 20	0.80 (.22)	0.94 (.11)	0.27 (.02)	0.98 (.06)	0.79 (.06)
Nov. 20	0.91 (.16)	1.21 (.09)	0.32 (.01)	1.05 (.02)	0.82 (.01)
Dec. 18	—	—	0.31 (.02)	1.07 (.03)	0.91 (.04)

[a] Not present.
[b] Not enough individuals for reliable statistics.

tical distribution data and rotifer data for 1979 and 1980 from the other techniques. By statistical analysis, we found that total numbers calculated from the techniques using Van Dorn samples were not significantly different from those of the vertical tows.

Zooplankton lengths. Except in 1979, at least 30 individuals of each major species were measured under a dissecting microscope, at each sampling date, to the nearest 30 μm, and the average size for that date calculated. In 1979 between 15 and 20 individuals were measured. The species most abundant and variable in size were divided into size classes and individuals assigned to them. For species that were too rare to permit counting of a significant number of individuals at any given date, all the individuals present were measured and the average length from measurements throughout the year was assigned to them. Average lengths for every sampling date of the last year of the present study (1980) are shown in Table 1.

Zooplankton weights. Except in 1979, average dry weights were calculated with the regression equations of dry weight vs. length given by Dumont, Van de Velde and Dumont (1975), and those for average values are given in Table 2. In 1979, the most abundant species were divided into size classes

TABLE 2. Formulae for calculating zooplankton dry weights from average lengths calculated during the present study.

Organism	*Formula*
Daphnia galeata and *D. retrocurva*	$W = 9.93 \times 10^{-8} \quad L^{2.56} + 2.97$
Diaphanosoma	$W = 1.88 \times 10^{-6} \quad L^{2.11} - 0.14$
Cyclopoids	$W = 2.00 \times 10^{-8} \quad L^{2.75} + 8.41$
Calanoids	$W = 8.40 \times 10^{-7} \quad L^{2.33} + 1.06$

W: Average weight in μg.
L: Average weight in μm.

and dry weights calculated for each size class independently, with the same equations of Dumont *et al.* (1975). These regressions were not checked for Lake Mendota zooplankton, but the same relationship was assumed for the same species in both studies. A carbon to dry weight ratio of 0.4 was used to convert to carbon biomass.

RESULTS AND DISCUSSION

Validity of the techniques used. According to Ruttner-Kolisko (1977), statistically reliable counts of rotifers can be obtained if more than 100 individuals of each species are counted. She compared three sampling methods for rotifers (vertical tows, Ruttner bottles and pump) and showed that the results were not comparable among the different techniques. Nevertheless, Ruttner-Kolisko concluded that numbers of rotifers could be used even if duplicates and/or sampling methods gave results differing by two fold, because the animals tend to change their numbers by several orders of magnitude throughout the year. In the present study, differences between duplicates and techniques were considerably smaller than those found by Ruttner-Kolisko. Average coefficients of variation (CV) for replicates taken with Van Dorn bottles were 19% for cyclopoids, 15% for calanoids, 31% for *Daphnia* species, 17% for *Daphnia galeata mendotae,* 20% for *Chydorus sphaericus,* 29% for other cladocerans, 26% for rotifers, and 15% for the most abundant rotifer, *Keratella cochlearis.*

When simultaneous samples taken with Van Dorn bottles and vertical tows were compared, average CV's were 22% for cyclopoids, 21% for calanoids, 47% for *Daphnia* species, 26% for *Chydorus,* and 38% for other cladocerans. Rotifers could not be counted in vertical tow samples because they were not retained by the zooplankton net. Coefficients of variation from vertical tow samples were only slightly higher than those for replicates of Van Dorn samples. Two way analyses of variance (ANOVA) without replication (Sokal and Rholf, 1969) were performed on abundances from vertical tows and Van Dorn samples for seven sampling dates to compare variability due to different sampling techniques with variability due to the different zooplankton species. As expected, the latter was always highly significant, due to the different population dynamics of different species. On the other hand, variability due to the different sampling techniques was never significant ($P > 0.05$), making possible comparisons of numbers obtained with all of the various techniques.

To check the variability due to horizontal location in the lake, on July 20, 1979 vertical tows and Van Dorn samples were taken at three stations in the eastern, central, and western parts of the lake. A three way ANOVA without replication (Sokal and Rohlf, 1969) was conducted, checking the variability of counts due to horizontal location, species, and sampling technique. Again, the latter was not significant ($P > 0.05$), while variability due to locations and to different species were both significant ($P < 0.05$ and $P < 0.001$ respectively). All this indicates that counts from any of the sampling methods can be used together in calculating zooplankton abundances, but that results from the central station, the station used for the present study, may not be easily extended to the whole lake, due to patchiness in the distribution of the organisms. Therefore, when values are given on an areal basis they should be understood as representing the central part of the lake.

Species composition. In the present study fourteen main species were found: 3 cyclopoid copepods (*Diacyclops bicuspidatus thomasi* (S. A. Forbes), *Mesocyclops edax* (E. A. Forbes), and *Acanthocyclops vernalis* (Fischer)), 3 calanoid copepods (*Leptodiaptomus sicilis* (S. A. Forbes), *L. siciloides* (Lilljeborg), and *Aglaodiaptomus clavipes* Schacht), 4 species of the genus *Daphnia* (*D. galeata mendotae* Birge, *D. pulex* Leydig, *D. parvula* Fordyce, and *D. retrocurva* Forbes), and 4 other cladocerans (*Chydorus sphaericus* (O. F. Müller), *Bosmina longirostris* (O. F. Müller), *Diaphanosoma leuchtenbergianum* Fischer, and *Leptodora kindtii* (Focke)). In addition, one cyclopoid copepod (*Tropocyclops prasinus* (Fischer)), one calanoid copepod (*Skistodiaptomus oregonensis* (Lilljeborg)), *Ceriodaphnia quadrangula* G. O. Sars, and *Ergasilus* sp. were observed occasionally in very small amounts.

Rotifers were identified to genus, except in the easily distinguished *Keratella cochlearis* (Gosse) and *K. quadrata* (Müller). The other genera present were *Polyarthra* Ehrenberg, *Brachionus* Pallas, *Asplanchna* Gosse, *Trichocerca* Lamarck, *Filinia* Bory de St. Vicent, *Conochilus* Hlara, and *Conochiloides* Hlara.

Annual cycle. The general pattern of zooplankton abundance and species composition was similar from year to year and to that found by Birge (1897) eighty years ago. We illustrate this general pattern with the data from 1979. During this year, we sampled 28 times with both vertical tows and Van Dorn bottles, and therefore, information was obtained on vertical distributions and total abundances and species composition of the zooplankton. Vertical distribution and total abundance for each organism or group of organisms are shown in Figures 1 to 13 for this year. However, since significant differences could be found from year to year, we will present data from other years when necessary. Each main group of organisms will be analyzed separately. Year-to-year variations are specifically treated in a later section.

1. *Cyclopoid copepods.* Birge (1897) mentioned only three species of cyclopoid copepods in Lake Mendota. *Cyclops Leuckartii,* corresponding to the currently recognized *Mesocyclops edax,* is the North American counterpart of the European *Mesocyclops leuckartii* (Cocker, 1943). The North American species followed the same type of annual cycle as the European species, being

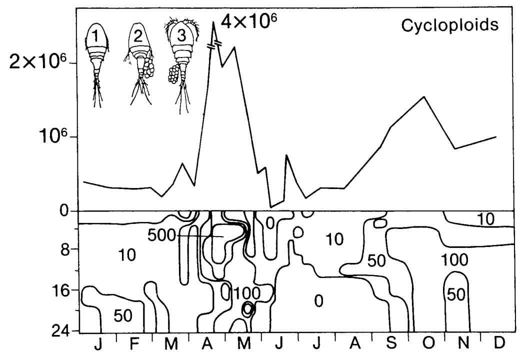

Fig. 1. Abundance, in individuals m^{-2} (upper panel), and vertical distribution in individuals l^{-1} (lower panel) of cyclopoid copepods during 1979. Depth is in meters. Adults and copepodites were pooled together. Drawings of animals are: 1, *Diacyclops bicuspidatus thomasi;* 2 *Mesocyclops edax;* 3, *Acanthocyclops vernalis. Tropocyclops prasinus* was rare most of the year.

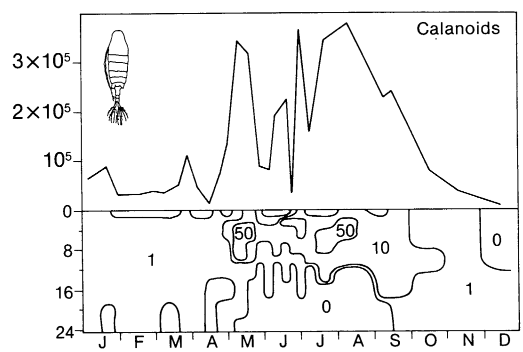

Fig. 2. Abundance, in individuals m^{-2} (upper panel), and vertical distribution in individuals l^{-1} (lower panel) of calanoid copepods during 1979. Depth is in meters. Adults and copepodites were pooled together.

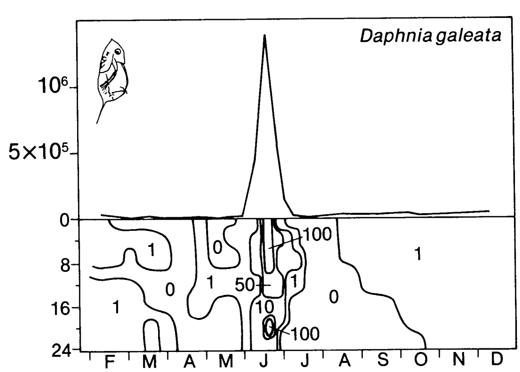

Fig. 3. Abundance, in individuals m^{-2} (upper panel), and vertical distribution in individuals l^{-1} (lower panel) of *Daphnia galeata mendotae* during 1979. Depth is in meters. Adults and juveniles were pooled together.

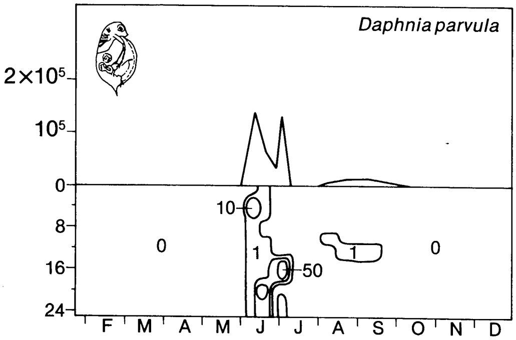

Fig. 4. Abundance and vertical distribution of *Daphnia parvula* during 1979. Symbols and units as in Fig. 1.

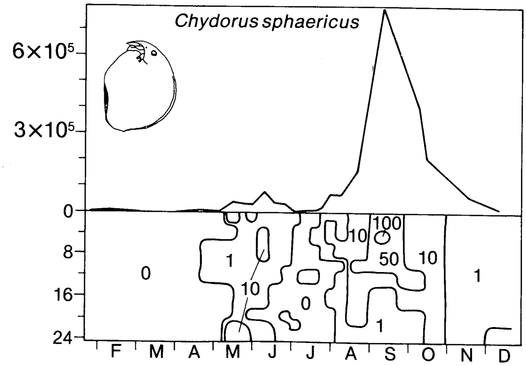

Fig. 7. Abundance and vertical distribution of *Chydorus sphaericus* during 1979. Symbols and units as in Fig. 1.

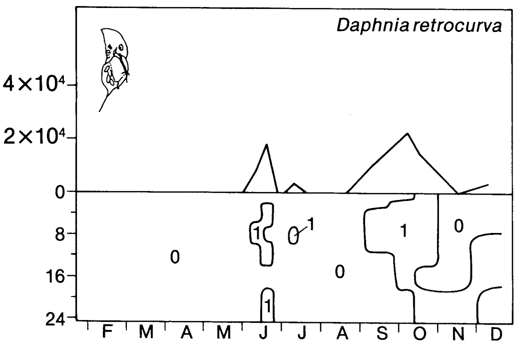

Fig. 5. Abundance and vertical distribution of *Daphnia retrocurva* during 1979. Symbols and units as in Fig. 1.

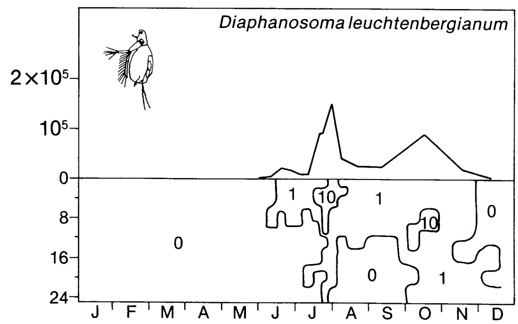

Fig. 8. Abundance and vertical distribution of *Diaphanosoma leuchtenbergianum* 1979. Symbols and units as in Fig. 1.

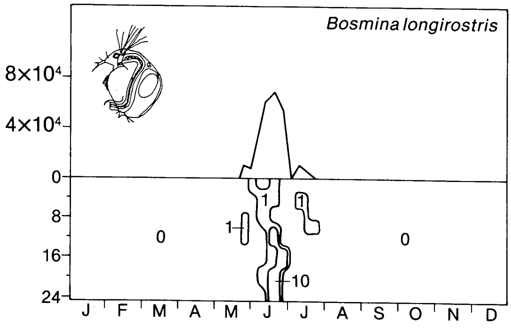

Fig. 6. Abundance and vertical distribution of *Bosmina longirostris* during 1979. Symbols and units as in Fig. 1.

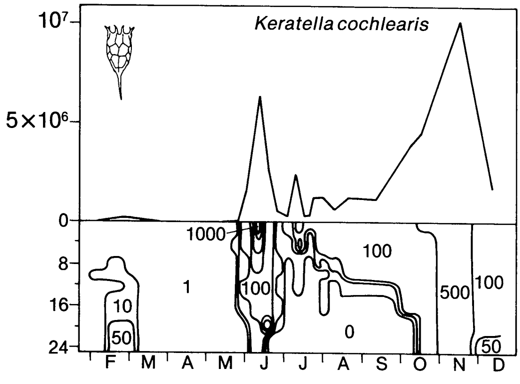

Fig. 9. Abundance and vertical distribution of *Keratella cochlearis* during 1979. Symbols and units as in Fig. 1.

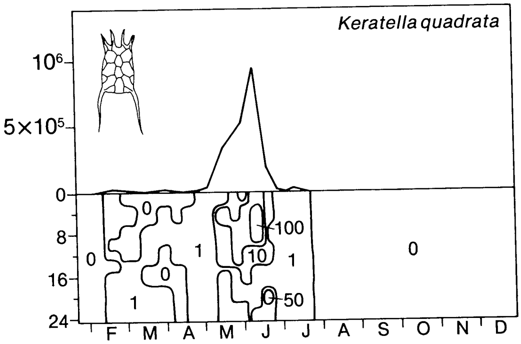

Fig. 10. Abundance and vertical distribution of *Keratella quadrata* during 1979. Symbols and units as in Fig. 1.

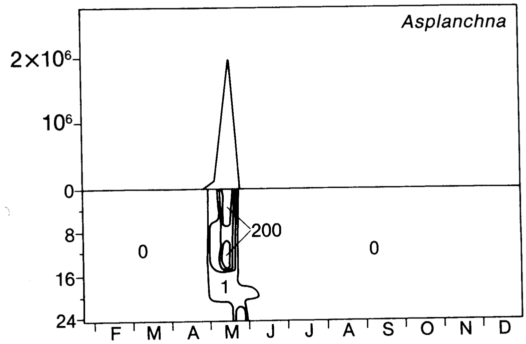

Fig. 13. Abundance and vertical distribution of *Asplanchna* sp. during 1979. Symbols and units as in Fig. 1.

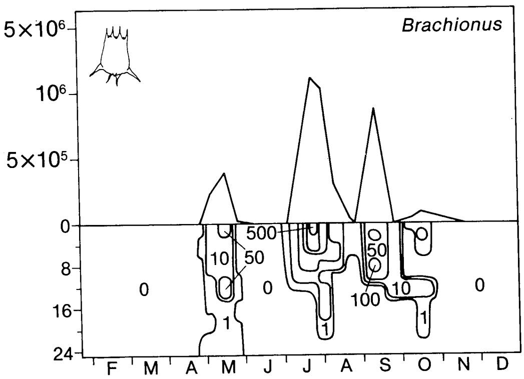

Fig. 11. Abundance and vertical distribution of *Brachionus* sp. during 1979. Symbols and units as in Fig. 1.

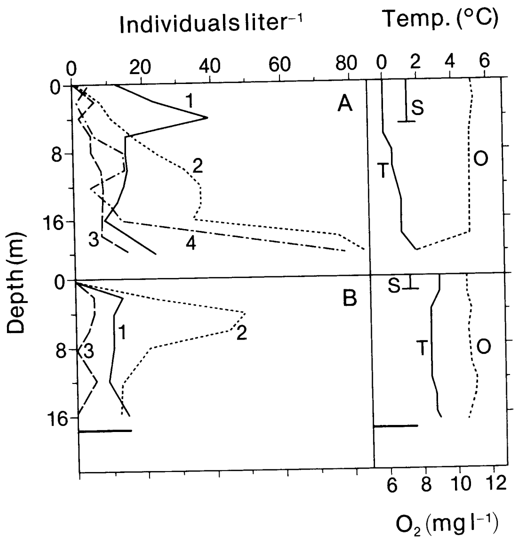

Fig. 14. Vertical profiles of zooplankton abundance (left hand panels) and physico-chemical parameters (right hand panels) for: A, February 21, 1979, and B. April 18, 1979. Symbols are: S, Secchi disk depth in meters; T, temperature in °C; O, oxygen in mg l^{-1}. The bar in panel B represents the bottom (a shallow station was sampled on this day due to inaccessibility of the central station because of ice). Organisms are: 1, Copepod nauplii; 2, Cyclopoid copepods (including copepodites and adults); 3, *Keratella quadrata;* 4, Calanoid copepods (including copepodites and adults).

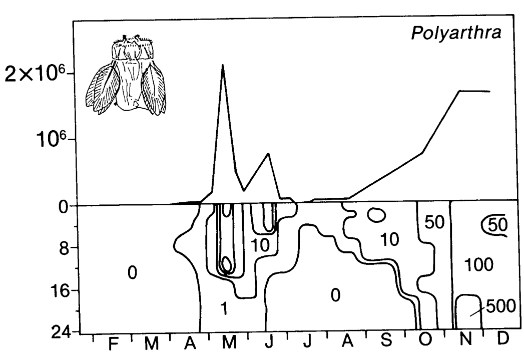

Fig. 12. Abundance and vertical distribution of *Polyarthra* sp. during 1979. Symbols and units as in Fig. 1.

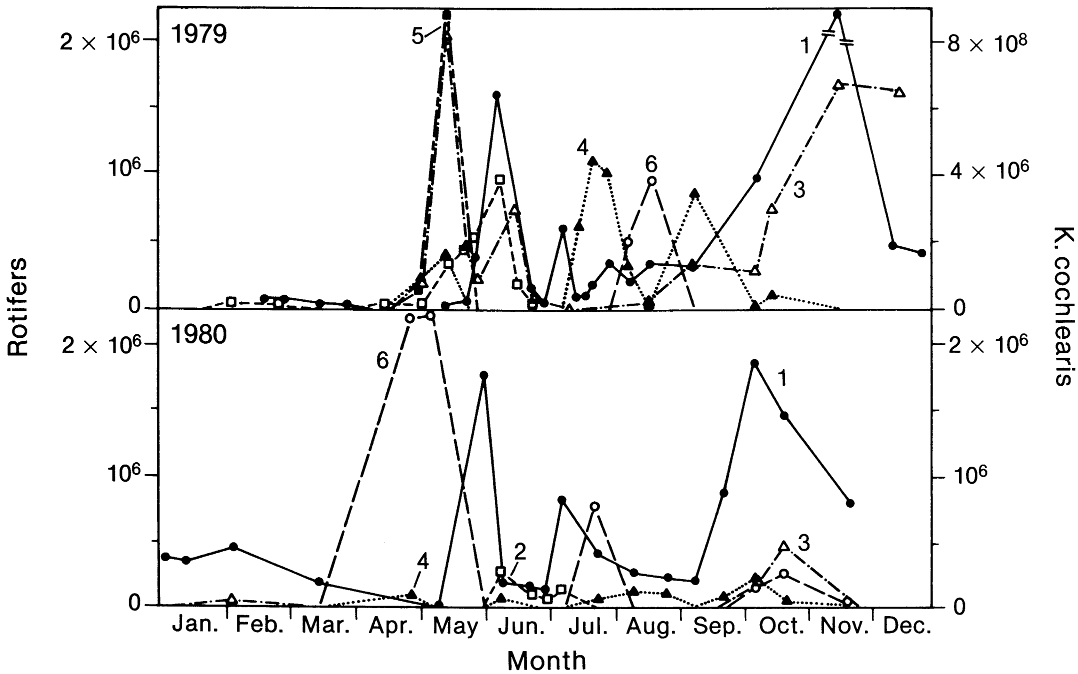

Fig. 15. Abundance in individuals m^{-2}, of rotifers during 1979, and during 1980. Animals are: 1, *Keratella cochlearis;* 2, *Keratella quadrata;* 3, *Polyarthra* sp.; 4, *Brachionus* sp.; 5, *Asplanchna* sp.; 6, *Conochilus* sp. in A and *Conochiloides* sp. in B. *K. cochlearis* is presented in a different scale.

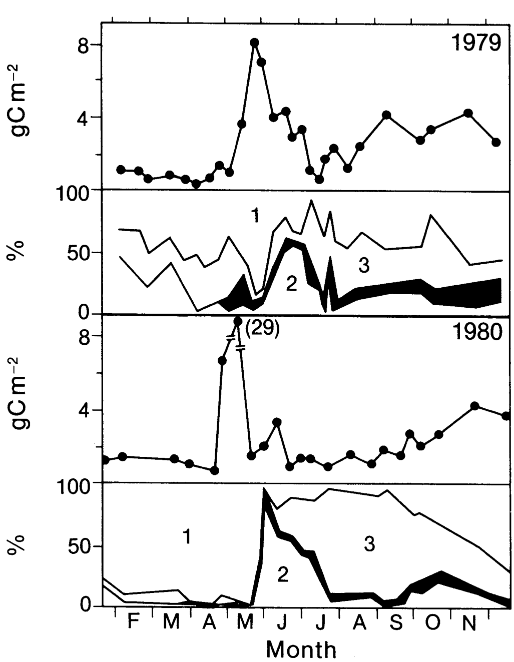

Fig. 16. Total zooplankton biomass during 1979 and 1980. A and C, Carbon weights in g m^{-2}. B and D, Percent biomass in different zooplankton groups. Rotifers are in black. Numbers are: 1, Cyclopoid copepods; 2, Cladocerans; and 3, Calanoid copepods.

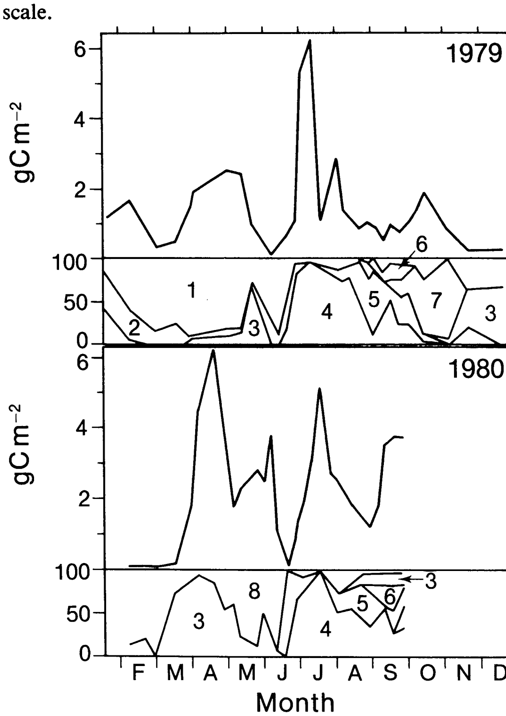

Fig. 17. Phytoplankton biomass during 1979 and 1980. Numbers are: 1, *Chlamydomonas* sp.; 2, *Cosmarium* sp.; 3, *Stephanodiscus astraea;* 4, *Aphanizomenon flos-aquae;* 5, *Lyngbya* sp.; 6, *Ceratium* sp.; 7, *Fragillaria* sp.; 8, *Cryptomonas* sp.

abundant and reproducing in the summer, and rare in the winter. *Cyclops pulchellus,* later reclassified as *Cyclops bicuspidatus* by Birge and Juday (1908), corresponds in modern taxonomy to *Diacyclops bicuspidatus thomasi.* Better information about this organism than in the 1897 paper can be found in Birge and Juday (1908), where they describe its summer diapause. Finally, *Cyclops brevispinosus* was considered to be a synonym for *Cyclops viridis* (Jurine) by Marsh in his revision of the North American *Cyclops* (Marsh, 1910). *Cyclops viridis,* in turn, is considered by Yeatman (1959) to occur only in a few cases in North America, but is referred in almost all cases to *Cyclops vernalis* Fischer, which corresponds to *Acanthocyclops vernalis* in modern taxonomy. The fourth species found in our study, *Tropocyclops prasinus,* does not appear in Birge's studies, but it had only very low numbers year-round and it could have been overlooked very easily by Birge, since most of his copepod taxonomy was done by Marsh using only a small part of his samples (Birge and Juday 1908).

Diacyclops bicuspidatus thomasi was the dominant organism during the late fall and

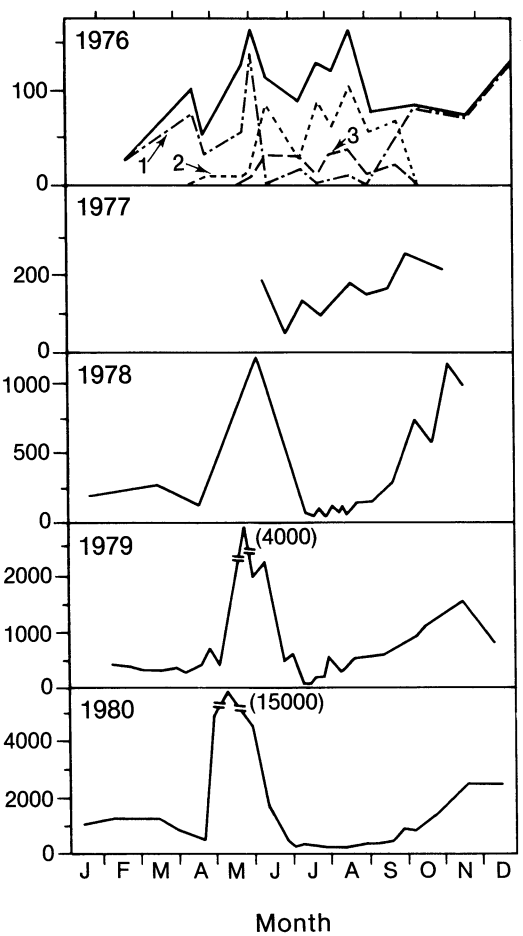

Fig. 18. Abundance of cyclopoid copepods from 1976 to 1980. Values have to be multiplied times 10^3 to obtain individuals per m^2. In 1976 individual species are also shown. Numbers are: 1, *D. b. thomasi;* 2, *A. vernalis;* and 3, *M. edax.*

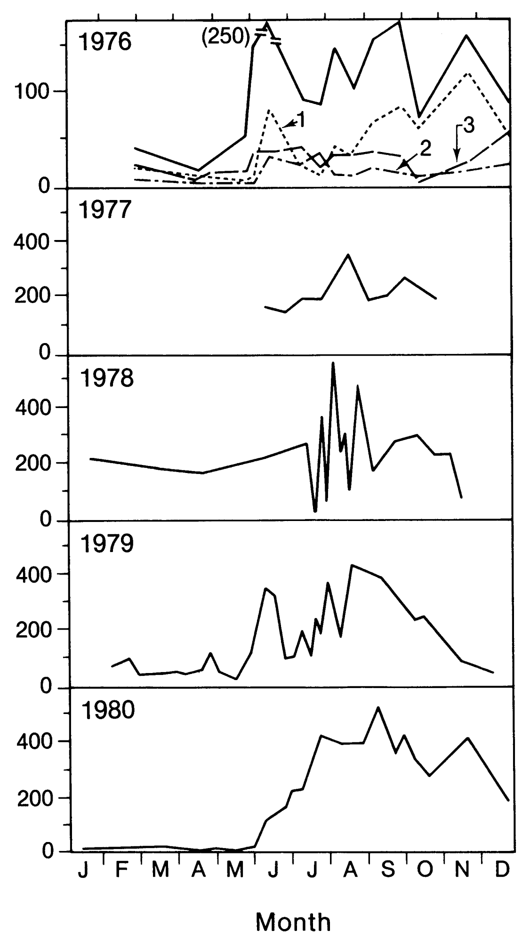

Fig. 19. Abundance of calanoid copepods from 1976 o 1980. Values have to be multiplied times 10^3 to obtain individuals per m^2. In 1976 individual species are also shown. Numbers are: 1, *L. siciloides;* 2, *L. sicilis;* and 3, *A. clavipes.*

winter, both in our study and in Birge's. Vertical distribution showed an accumulation of *D. b. thomasi* towards the bottom of the lake during this time of the year (see Fig. 1 and Fig. 14a). Temperature was one to two degrees warmer than at the surface and throughout most of the water column (Fig. 14a), and this might attract the organism. From February to March, the animals slowly rose from the bottom, establishing themselves at four meters by the end of March (Fig. 14b), and increasing from then on to produce the annual maximum in May. This peak of abundance represented the highest biomass of the whole year, with concentrations of 1.8×10^6 ind. m^{-2} in 1896 and 1.48 $\times 10^7$ ind. m^{-2} in 1980, which accounted for 90% of the total zooplankton biomass (Figs. 16 and 22). The May peak appeared every single year in both Birge's and our studies, and there was a sharp crash shortly after the peak had appeared. According to Birge (1897), this crash was due to a lack of food. Fryer (1957) established the carnivorous habits of most cyclopoids, but Hutchinson (1967) pointed out that small cyclopoids, such as *D. b. thomasi,* would feed mainly by

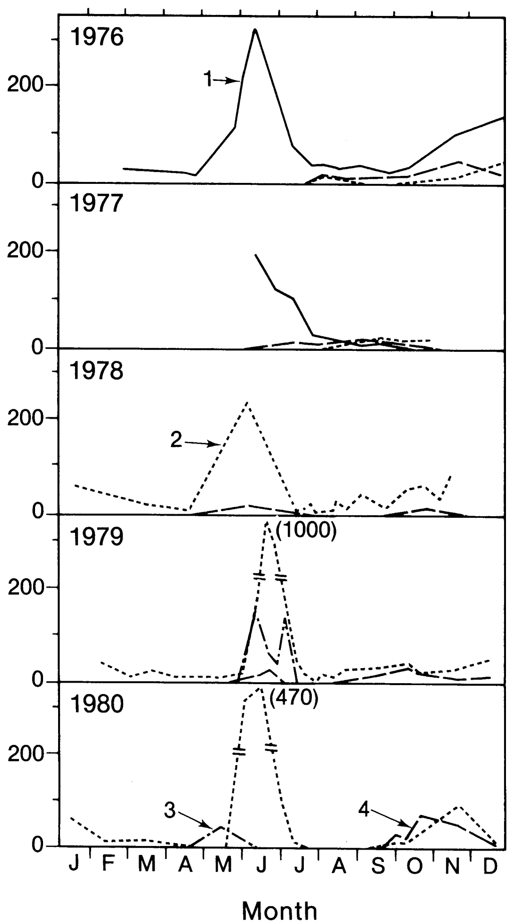

Fig. 20. Abundance of members of the genus *Daphnia* from 1976 to 1980. Values have to be multiplied times 10^3 to obtain individuals per m^2. Numbers are: 1, *D. pulex;* 2, *D. g. mendotae;* 3, *D. parvula;* and 4, *D. retrocurva.*

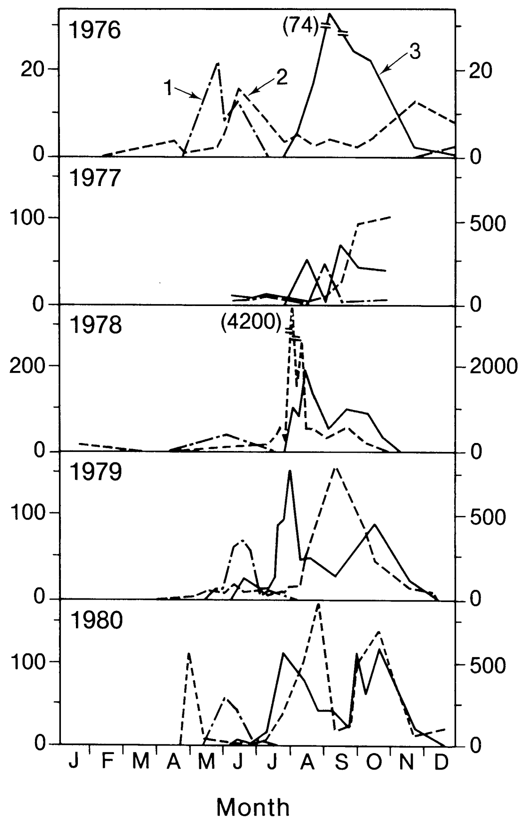

Fig. 21. Abundance of cladocerans not belonging to the genus *Daphnia* from 1976 to 1980. Values have to be multiplied times 10^3 to obtain individuals per m^2. The scale on the right is for *Chydorus* only (number 2). The scale on the left is for *Bosmina* (number 1) and *Diaphanosoma* (number 3).

grabbing algae. Our feeding experiments showed that it could also eat bacteria, although at very low rates, from 0.1 to 1.0 ml ind^{-1} day^{-1} (Pedrós-Alió and Brock, 1983). During 1979, the May peak started when the alga *Chlamydomonas* was at its maximum (Fig. 17a). The two organisms increased and disappeared following perfect "predator-prey" curves (see Figs. 16a and 17a). In 1980, there was an early peak of the diatom *Stephanodiscus* (Fig. 17b), and *D. b. thomasi* followed it at the time that the diatoms disappeared and the flagellate *Cryptomonas* reached its maximum (Figs. 16b and 17b). In both cases, the algae almost

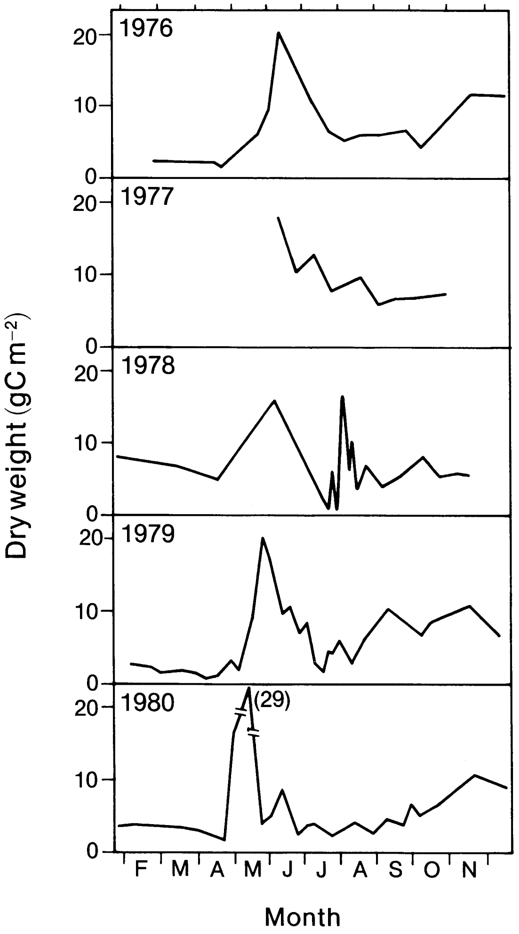

Fig. 22. Total zooplankton biomass. Dry weight in g carbon per m^2 for the five years of the present study.

completely disappeared from the lake in mid-June, perhaps thus causing the crash of *D. b. thomasi.*

Birge and Juday (1908) discovered this peak of *D. b. thomasi* to be composed mainly of immature individuals which gradually descended towards the sediment and entered diapause as the copepodite IV stage. Lack of food and rising temperatures in the epilimnion, and anaerobiosis in the hypolimnion, were the factors inducing *D. b. thomasi* to enter diapause. The same summer resting stage has been described in other lakes (Moore 1939, Cole 1953) and at least one case of winter encystment has also been described in Marion Lake, British Columbia (McQueen 1969). Sealed bottles with mud samples showed a fine layer of live, slowly-moving animals at the mud-water interface after several months of being devoid of oxygen, demonstrating the animal's ability to survive in the anaerobic hypolimnion throughout the summer.

Towards the fall, more and more copepodites left their cocoons and reached the cooler and oxygenated waters after the lake overturned, and this was reflected in the increasing abundance of the organism in the plankton starting in late September and reaching a plateau in late December, about the time the lake froze. As shown by the presence of egg-bearing females and nauplii, winter populations reproduced at a slow pace and thus were able to compensate losses and maintain more or less constant numbers under the ice until ice-out occurred, at which time the population started to produce another spring peak.

D. b. thomasi was the most abundant crustacean in Lake Mendota, a feature common to many North American lakes (Watson, 1974; Hutchinson, 1967; McQueen, 1969). However, the annual cycle of this organism in Lake Mendota, both in Birge's and in our study, was different from the cycle in other lakes such as L. Ontario (Nauwerck et al., 1972), L. Erie (Watson et al., 1973) or Marion Lake (McQueen, 1969).

There is a common alternation between

Diacyclops and *Mesocyclops* in many lakes (Hutchinson, 1967). In these cases, *Diacyclops* dominates during the winter while *Mesocyclops* is more abundant during the summer. In some cases, *M. leuckartii*, the European counterpart of *M. edax*, has been found to undergo winter diapause (Fryer and Smyly, 1954), replacing *Diacyclops* in the summer (Cole, 1955). Thus, *M. edax* in L. Mendota followed the general pattern for temperate lakes. According to Fryer (1957), *M. edax* is carnivorous, preferentially eating small cyclopoids, *Diaphanosoma* and rotifers, and thus it would find abundant prey in the summer fauna of the lake.

Acanthocyclops vernalis followed the same pattern as *M. edax*, although generally in lower numbers. Together, these species accounted for all the summer cyclopoids in the lake (Fig. 1). *A. vernalis* is also a large aestival, carnivorous cyclopoid (Cocker, 1943; Fryer, 1957). The expected competition for food between *A. vernalis* and *M. edax* might not have occurred because of their size differences. *Tropocyclops prasinus*, found at all times during the year in very low numbers, is a common constituent of the plankton in the Great Lakes and inland lakes of Wisconsin (Hutchinson, 1967).

2. *Calanoid copepods*. Birge reported only one species of calanoid copepod: *Diaptomus oregonensis* Lillj. and described a life cycle which consisted of a stable winter population with no reproduction and no change in numbers, a small peak in June, a middle summer minimum, and a second peak in September. Birge found reproduction from May to September, as shown by the presence of ovigerous females, but there were also losses due to predation by *Leptodora*, invertebrate larvae such as *Chaoborus*, and planktivorous fish, especially perch. After October, when lower temperatures developed, the population started to decrease. Some of the adults overwintered, while some produced a few nauplii which slowly developed under the ice. The same type of cycle, with two summer generations, was found by Langford (1938) for *Skistodiaptomus oregonensis* in Lake Nipissing and by Davis (1961) in Lake Erie. This suggests that *S. oregonensis* was, in effect, the most abundant calanoid in the 1890s in Lake Mendota, but that Birge did not recognize the possible presence of other species due to the amount of work necessary to differentiate species (as he states, Birge, 1897, p. 326). In our study, *S. oregonensis* was the least abundant calanoid species and this is the main difference between the crustacean plankton studied by Birge and that found by us.

We found three species occurring together in the plankton of Lake Mendota (Figs. 2 and 19). This is a common phenomenon, as Davis (1961) found three of our species and two more coexisting in Lake Erie. He found that *Leptodiaptomus siciloides* and *S. oregonensis* reproduced mostly in the summer, while *L. sicilis* did so in the winter and spring. Eddy (1930) described *L. siciloides* and *L. sicilis* coexisting in Reelfoot Lake, the first being abundant year-round and the second appearing only in November. Wilson (1955) found *Aglaodiaptomus clavipes* and *L. siciloides* living together in Boulder Dam (Nevada) and Cole (1961) found the same two species in some of the Salt River impoundments in Arizona, associated with the cyclopoid *Acanthocyclops vernalis*. It seems that different species of diaptomids can coexist due to differences in size, food requirements, vertical distribution, reproductive season, etc. In our study, *L. siciloides* was the most abundant species year-round, but *L. sicilis* and *A. clavipes* followed closely, the three species being present throughout the year. It seems reasonable that the larger the lake, the more species of diaptomids can coexist, since there are more niches available (Hutchinson, 1967), and Lake Mendota fits nicely between the small ponds in Arizona with two species (Cole, 1961) and the large lakes such as Lake Erie with five species (Davis, 1961). In summary, although the main species was different in the 1970s than in the 1890s, the pattern of abundance of calanoid copepods was very similar to that found by Birge.

3. *The genus Daphnia.* The various species of the genus *Daphnia* were the most abundant cladocerans in Lake Mendota. Four species were found in the present study, three of them the same species found by Birge: *D. galeata mendotae, D. retrocurva,* and *D. pulex.* A fourth species, *D. parvula,* which was not mentioned by Birge, appeared in the last two years of the present study. The genus *Daphnia* constituted from 80 to 60% of the total zooplankton biomass during the month of June (Fig. 16).

D. galeata mendotae was referred to as *D. hyalina* in Birge's paper (Hutchinson 1967, p. 611). Birge himself redescribed it later as *D. g. mendotae* (Birge, 1918). It behaved in 1895 and 1896 as a perennial species with a fairly variable cycle, always with a small peak in May-June of about 300 ind. m^{-2}, and either no peak (1895) or a rather large peak (1896) of 500 ind. m^{-2} in October. During the two first years of the present study, *D. g. mendotae* was found in very low numbers, mostly during the summer (Fig. 20), but from 1978 on, it replaced *D. pulex* and became the most abundant *Daphnia* species in the lake. From 1978 to 1980, *D. g. mendotae* showed a very consistent peak in June, and low, oscillating numbers for the rest of the year (see results for 1979 in Fig. 3). The June peak was much larger than any peak reported by Birge for any *Daphnia* species, reaching 1.02×10^6 ind. m^{-2} in 1979 (Fig. 3). While this maximum of abundance lasted, *Daphnia* constituted between 50 and 60% of the total zooplankton biomass (Fig. 16). This type of behavior, with a single sharp peak in the whole year, has been observed in *D. galeata* in a Swedish lake (Axelson, 1961) where temperature was never above 17°C, but in most American lakes *D. g. mendotae* always exhibits two peaks, one in late spring and one in the fall (Birge, 1897; Borecky, 1956; Hall, 1962). The different cycle in Lake Mendota is probably due to the recurrent cyanobacterial blooms during the summer. Cyanobacteria can have negative effects on zooplankton in several ways. Members of the genus *Daphnia* cannot eat the large flakes of filamentous *Aphanizomenon* (Holm et al., 1983) and, therefore, are unable to reproduce during the summer, thus giving rise to a second peak in the fall. In addition, many *Microcystis* species are toxic to zooplankton (DeBernardi et al., 1981). Moreover, daphnids are less efficient than calanoids at avoiding filamentous and other blue-green algae, and unlike calanoids, daphnids are not able to feed selectively on smaller edible algae (Richman and Dodson, 1983).

The collapse of the June daphnid peak was probably due to a combination of lack of food and predation by fishes. Fish ate large quantities of *Daphnia* when the cladoceran accumulated locally (McNaught and Hasler, 1961). *Leptodora,* on the other hand, did not play any major role in the disappearance of *Daphnia* in Lake Mendota, since it only appeared in July, when the *Daphnia* population had already declined. *Leptodora,* however, could help to maintain low summer populations once the peak had crashed, by eating the juveniles, as Hall (1962) found in Base Line Lake. The most obvious factor in the disappearance of the *D. g. mendotae* peak was lack of food. Both in 1979 and 1980 there was a dramatic reduction in phytoplankton biomass coincidental with the *Daphnia* peak (Figs. 16 and 17). At its maximum, *D. g. mendotae* had a biomass of 6.7 g C m^{-2}, while there were only 0.057 g C m^{-2} of phytoplankton and 0.203 g C m^{-2} of bacteria in the lake (Pedrós-Alió and Brock, 1982). The *Daphnia* probably eliminated the algal spring bloom formed by easily edible algal species of the genera *Cryptomonas* and *Stephanodiscus,* thus leaving the stage set for the appearance of cyanobacteria and the summer fauna in early July.

D. pulex is considered to be a cold water species with a rather variable annual cycle. It presented low oscillating peaks of population during the summer of 1895 and a sharp peak in May of 1896 (Birge, 1897). In our study, *D. pulex* had a similar large peak in early June and low numbers the rest of the year during 1976 and 1977, but disappeared almost completely afterwards (Fig. 20). The substitution of *D. g. mendotae* for *D. pulex* was rather dramatic and it probably reflected the incidence of heavy fish predation in 1978 and after. *D. pulex* was considerably larger than *D. g. mendotae,* and this would give the latter a competitive advantage when planktivorous fishes were present (Brooks and Dodson, 1965). As a matter of fact, we observed cisco *(Coregonus artedii)* appearing in large numbers as a single size class in 1979-1980, while it had been absent from 1976 to 1977.

D. parvula appeared only in 1979 and 1980. Although in 1979 it was present at the same time as *D. g. mendotae,* the two species seemed to avoid each other both in depth and slightly in time (Figs. 3 and 4), so that direct competition did not occur. *D. parvula* seems to replace *D. retrocurva* in the Southern U.S. (Hutchinson, 1967, p. 818). However, during the present study, *D. retrocurva* did not show any differences in life cycle when *D. parvula* was present from when it was absent. Thus, these two species did not seem to compete in Lake Mendota.

During the present study, *D. retrocurva* behaved in almost the same way as in 1895, being an aestival species with numbers around 5×10^4 ind. m^{-2} from July to December (Fig. 5). However, a peak such as that found in 1896, with 3×10^5 ind. m^{-2}, did not occur in any of the years of the present study.

If the genus *Daphnia* is considered as a whole, the annual cycle was almost identical to that found by Birge (1897), with peaks in spring and autumn, and variable numbers during the summer. But when individual species are taken into account, differences within years can be found both in Birge's study and in ours.

4. *Other cladocerans.* Cladocerans other than *Daphnia* in Lake Mendota could be divided into spring and summer species. During the present study, *Bosmina* and *Ceriodaphnia* appeared almost exclusively in the spring, generally coincidentally with the *Daphnia* peak and with the disappearance of the easily edible phytoplankton. This behaviour seems fairly typical for *Bosmina longirostris* (Fig. 6; Wesenberg-Lund, 1904; Patalas, 1956) and it was rather constant from 1976 to 1980. The maximum reached 7×10^4 ind. m^{-2} except in 1978 when it was less abundant (Fig. 21).

Ceriodaphnia, on the other hand, is considered to be a pond species (Hutchinson, 1967, p. 619) and its appearance in the plankton was, accordingly, erratic. It was only recorded a few times, and always in fairly low numbers, once in 1976, never from 1977 to 1978, once in 1980, with a small peak being detected in June 1979 coinciding with the peaks of *Daphnia* and *Bosmina.*

The summer species of cladocerans were *Diaphanosoma leuchtenbergianum, Chydorus sphaericus* and *Leptodora kindtii.* In the summer, after the lake had become firmly stratified, the main phytoplankton species were cyanobacteria (blue-green algae), mainly *Aphanizomenon* and to a lesser degree *Microcystis* and *Lyngbya* (Fig. 17). *Daphnia* does not eat *Aphanizomenon,* and the same seems true for smaller cladocerans and calanoid copepods. Thus, these summer zooplankters graze primarily on the smaller sized, less abundant, eukaryotic algae, which form a small percentage of the phytoplankton biomass at the time (Fig. 17). The species composition thus shifts from the relatively large *D. g. mendotae* to the smaller *Diaphanosoma* and *Chydorus.*

Chydorus sphaericus is a littoral species which appears in the plankton mainly when there are cyanobacterial blooms (Hutchinson, 1967). It has been suggested that *Chydorus,* being a littoral particle scraper, would be able to handle the larger cyanobacteria as if they were particles and somehow eat them, for example by sucking

Aphanizomenon filaments "spaghetti style." Thus, this could explain the abundance of *Chydorus* in the summer plankton (Fig. 7). Its oscillations were quite variable from year to year, presenting two peaks in 1976, one peak from 1977 to 1979, and three peaks in 1980 (Fig. 21). These peaks were found from May to November in different years. Birge found *Chydorus* in low numbers with very small peaks (100 to 300 ind. m^{-2}) in July 1895 and September 1894, and three peaks of 400 ind. m^{-2} in July, 750 ind. m^{-2} in September, and 400 ind. m^{-2} in October of 1896, thus showing the same type of variability that we found. *Chydorus* seemed not to avoid the lower depths as much as other cladocerans (Fig. 7), not even during the period when the hypolimnion was anaerobic.

From 1976 to 1980, *Diaphanosoma* changed slowly from having a cycle with only one wide peak in late August (1976, see Fig. 21) to presenting two clearly distinct peaks in late July and in September (1980, see Fig. 21). Both types of behavior have been observed in this organism (Marsh, 1893; Birge, 1897; Patalas, 1954; Wells, 1960). Birge found very low numbers in September-October of 1894 and 1895, and a sharp peak of 1.5×10^5 ind. m^{-2} in 1896. The highest concentration found in the 1970s varied in different years between 100 and 4×10^5 ind. m^{-2}. It seems a widely extended feature of cladocerans to be able to shift back and forth between cycles with one and two annual peaks. This has been observed in Lake Mendota for *Diaphanosoma, Chydorus* and *D. retrocurva* (present study; Birge, 1897). Changes in maximum abun-

TABLE 3. Comparison of two different techniques in the determination of the abundance of *Leptodora kindtii* in Lake Mendota, 1980.

Date	*Individuals per m²*	*Total individuals counted*	*Percent of sample counted*	*Sampling method*
Jan. 14	0	0	100	Van Dorn
Feb. 7	0	0	100	Van Dorn
Mar. 17	0	0	100	Van Dorn
Apr. 1	0	0	100	V. tow[a]
Apr. 22	0	0	100	V. tow
Apr. 29	0	0	100	Van Dorn
May 12	0	0	100	Van Dorn
June 2	0	0	100	Van Dorn
June 11	0	0	100	Van Dorn
June 24	0	0	100	Van Dorn
July 1	0	0	100	Van Dorn
July 8	1600	2	100	Van Dorn
July 23	1300	1	100	Van Dorn
Aug. 12	2000	2	3	V. tow
Aug. 26	3000	9	10	V. tow
Sept. 8	500	15	100	V. tow
Sept. 22	2000	55	100	V. tow
Sept. 29	2000	1	2	V. tow
Oct. 6	1000	30	100	V. tow
Oct. 20	0	0	1	V. tow[b]
Nov. 20	1000	1	4	V. tow[a]
Dec. 18	0	0	4	V. tow

[a] Vertical tow from 23 m to the surface.
[b] Vertical tow from 23.5 m to the surface.

dances of cladocerans are probably in accordance with changes in food availability, competition, and predation.

Leptodora kindtii was always present in very low numbers, appearing in the plankton in July and disappearing towards October (Table 3). The extreme rarity of this animal makes numbers in Table 3 not completely reliable, due to the few individuals counted. *Leptodora* always appeared a few weeks after the collapse of the June *Daphnia* peak, so that, contrary to what happened in Base Line Lake (Hall, 1962), *Leptodora* did not play a significant role in the disappearance of *Daphnia* in Lake Mendota. Birge also found *Leptodora* present in very low numbers during the summer, and this has been observed by several authors (Wesenberg-Lund, 1904; Findenegg, 1953; Nauwerck, 1963).

5. *Rotifers.* No comparisons are possible for rotifers, since there are no previous quantitative studies of the rotifers of Lake Mendota. Only studies of Harring and Myers (1921) considered the rotifers of Wisconsin, but they were mostly concerned with the taxonomy and distribution of the different genera and not with quantitative, ecological studies. All the genera we found appeared in their 1921 list of species (Harring and Myers, 1921). The organisms found belong to all the common planktonic genera and are widely distributed (Figs. 9 to 13, and 15). Numerically some of them were very abundant, but in terms of biomass they always constituted a very small portion of the whole zooplankton biomass (Fig. 16).

All the rotifers were extremely rare (*Keratella* spp.) or completely absent (the other genera) from the winter plankton. Both *Keratella* species, *Polyarthra,* and *Asplanchna* had one or two peaks, usually one in the spring and one in the fall, but were absent from the lake during summer stratification. *Brachionus* and *Conochilus,* on the other hand, were more abundant during lake stratification. *K. cochlearis* was the most abundant rotifer as well as the one with the most constant annual cycle. It had a peak in June, a small peak in early July, and its largest peak in October or November (Figs. 9 and 15). The other genera tended to have peaks which did not overlap (Fig. 15) and which substituted for each other from spring to fall.

Year-to-year variations: 1976-1980. Considerable year-to-year variation occurred in the general annual cycle described in the previous section. Most of the detailed changes have already been discussed. Here, we will only give a systematic summary of the changes found. The main body of data (with numbers and biomass for each species, each depth, and each sampling date of the five years of the present study) can be found in Pedrós-Alió (1981). For conciseness, the organisms have been grouped and their abundances represented in Figures 18 to 21 and total zooplankton biomass is presented in Figure 22. Three types of changes among years were found and will be discussed separately below: 1) species composition, 2) maximum abundances of certain species, and 3) timing of the maxima.

1. *Species composition.* The most dramatic change in species composition was the substitution of *D. g. mendotae* in 1979 and 1980 for *D. pulex,* which had been the dominant cladoceran in the previous years (Fig. 20). This substitution was almost complete and very few individuals of *D. pulex* could be observed after 1978. The remaining changes in species composition were due to the presence of certain species (in substantial numbers) during some years, but not others. *D. parvula* appeared in 1979, presenting high numbers in the metalimnion immediately before and after the main *D. g. mendotae* peak (Fig. 4). In 1980 there was again a small peak, but no individuals of this species were observed previous to 1979. Finally, *Ceriodaphnia quadrangula* was observed in significant numbers only in February 1976 and in June of 1979 and 1980.

2. *Maximum abundances.* It can be easily seen in Figures 18 to 21 that maximum abun-

dances of many species were different from year to year. For example, the peak of *D. g. mendotae* in June was 230 ind. m^{-2} in 1978, 1000 ind. m^{-2} in 1979, and 470 ind. m^{-2} in 1980. The May peak of *Diacyclops* reached 150 ind. m^{-2} in 1976, 1200 ind. m^{-2} in 1978, 4000 ind. m^{-2} in 1979, and 14700 ind. m^{-2} in 1980. These are only the most spectacular changes in abundance, but variations were observed in most species.

3. *Timing of species maxima.* Some of the species found were reasonably constant in their annual cycles, such as *Diacyclops* and *D. g. mendotae.* On the other hand, species such as *Diaphanosoma* and *Chydorus* were rather variable in the timing of their appearance as well as in the number of peaks per year (Fig. 21). In general, the species present during the winter and spring had very predictable peaks and cycles, while the summer species were variable.

When a statistical test was run to test for differences between our study and Birge's (Pedrós-Alió and Brock, 1985), it was found that differences among years within each study were higher than differences between the two studies. Thus, for example, 1895 was very different from 1896 and close to 1978, and 1976 differed more from 1979 and 1980 than from 1895 or 1896. Therefore, although clear year-to-year variations were found, no significant trend with respect to Birge's study could be detected, indicating that the lake has had the same conditions for the past eighty years.

Acknowledgments

Winter samples for 1978 were kindly provided by R. Lathrop from the Wisconsin Department of Natural Resources. Samples from 1976 were gathered by Dr. V. Watson, then at the Department of Botany of the University of Wisconsin. Phytoplankton biomass was measured by T. H. Gries and J. Sesing, in the Department of Bacteriology.

This work was supported by NSF grant DEB-8212459 to T. D. Brock and the Northern Lakes component of the Long-Term Ecological Research Program of the National Science Foundation (DEB-8012313). Carlos Pedrós-Alió was a recipient of a Fulbright-Hays grant from the United States-Spain Cultural Exchange Program.

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A STABLE ARTIFICIAL SUBSTRATE DEVICE (TRI-BASKET SAMPLER) FOR COLLECTING MACROINVERTEBRATE SAMPLES FROM STREAMS AND RIVERS

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The quantitative collection of aquatic macroinvertebrates for the purpose of environmental impact assessment has always presented some sampling problems. Hellawell (1968) provides a review of the major benthos sampling devices and techniques, including artificial substrate samplers. Although the utilization of artificial substrates is now widely accepted (Cairns, 1982), advantages and disadvantages to these techniques exist. Rosenberg and Resh (1982) concluded that the habitat to be sampled will usually dictate the sampling device used. The remainder of this paper describes a sampler we feel provides a durable, simple, and efficient device for collecting benthos under certain habitat conditions.
system to be used in areas where the natural habitat was composed largely of pebble and cobble (50–250 mm in diameter). Additionally, we wanted the system to withstand fluctuations in river discharge, while providing physical stability and positive direction-of-current orientation. Unlike the standard Surber sampler, the device had to be versatile enough to be used in shallow water and, with the use of S.C.U.B.A., deeper water. We also needed a sampler which would generally minimize the effect of siltation, allow for the collection of samples without loss of fauna, be relatively inconspicuous to minimize vandalism, and provide some measure of within-sampler variation.

The tri-basket sampler (Fig. 1) was devised to satisfy the design criteria previously stated. It is composed of three modified barbeque baskets like those described by Anderson and Mason (1968). Each basket is 18 cm (7 in.) in diameter by 13 cm (5 in.) in length.

Attached to the base of each basket is a 6 mm-(0.25 in.) thick Masonite plate 18 cm (7 in.) in diameter to give stability to each basket. Twelve, 5 cm (2 in.) in diameter unlapped porcelain balls were used as substrate material within the basket.*

The baskets are mounted on steel pipes 30 cm (12 in.) long by 3.2 cm (1.25 in.) in diameter (outside diameter). These pipes are attached to a triangular steel frame constructed of three 76 cm (30 in.) pieces of 5 cm (2 in.) angle iron welded together (60° inside angle). The configuration of the steel frame reduces standing wave effects from the lead basket on those to its sides. Small steel pipes to accept the ones supporting the baskets are welded in the corners of the frame. These pipes are 13 cm (5 in.) in length by 4.1 cm (1.75 in.) in diameter (O.D.). These pipes allow for adjustment in basket height above the frame (achieved by placement of holes in basket pipes).

The baskets can be removed from the frame at the top or bottom by releasing either one of the 6 mm (0.25 in.) clevis pins. Although the sampling device maintains location on the natural substrate well by virtue of its weight 17 kg (37 lb) and configuration, additional security is provided by utilizing a

* **Sources of Equipment:** Bar-B-Q Tumble Basket, Paramount Housewares, 4770 East 50th St., Los Angeles, California 90058. Two-inch, unlapped porcelain balls, Ferro Corporation, Porcelain Plant, P.O. Box 858, East Liverpool, Ohio 43920.

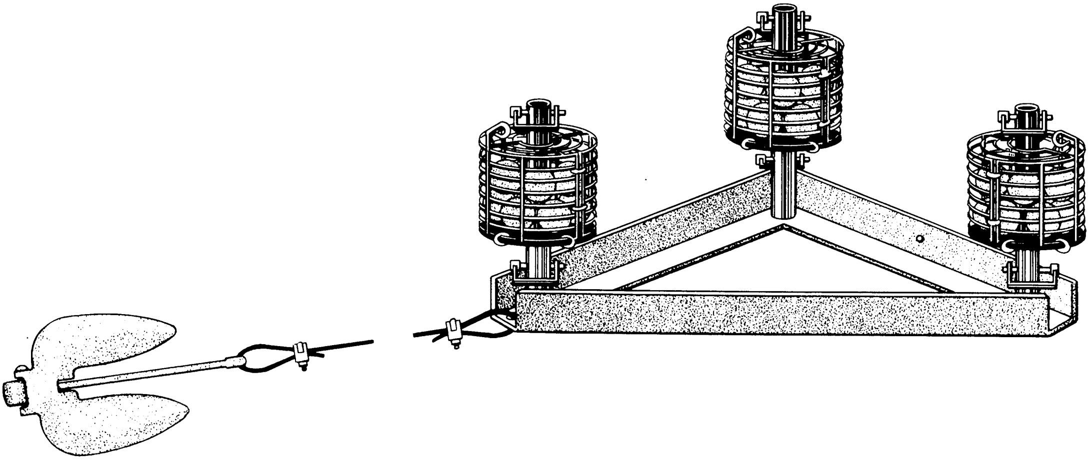

Fig. 1. Tri-Basket Sampler.

Table 1. A comparison of major colonizing groups (average percent comparison) and numbers of species (average number/sample) for tri-basket and natural substrate (Surber sample).

River	*Substrate Type*	*Number of Samples*	*Trichoptera (%)*	*Ephemeroptera (%)*	*Diptera (%)*	*Oligochaeta (%)*	*Turbellaria (%)*	*Number of Species*
Wisconsin River, WI Summer	Tri-basket	18	47	4	30	9	8	31
	Natural	18	49	3	22	3	16	26
Wisconsin River, WI Fall	Tri-basket	18	45	5	18	31	1	28
	Natural	18	69	2	17	3	5	23
Catawba River, SC	Tri-basket	21	67	16	10	3	2	27
	Natural	5	44	13	15	8	18	16

9 kg (20 lb) navy anchor. The anchor is attached to the sampler with plastic coated steel cable (0.5 cm) (0.38 in.) and several cable clamps. Samples are collected without loss of fauna by placing plastic or nylon mesh bags over each basket before removal from the frame.

A comparison of the faunal composition on the tri-basket sampler and the natural substrate was conducted to determine sampler biases for different groups (Table 1). In general, those taxa that were dominant on the natural substrate were also dominant on the tri-basket sampler. Likewise, within-sampler variation was looked at to determine sampling efficiency (Table 2).

The tri-basket sampler was found to be a stable sampling system to obtain benthic macroinvertebrate specimens. The weight of the sampler maintains the proper position and orientation on the stream bottom, par-

Table 2. A comparison of within-sampler variation (coefficient of variation) for density and number of species from four different river systems.

River	*Number of Samples*	*Number of Species*	*Density*
Wisconsin, WI	18	13.2%	15.4%
Escanaba, MI	7	12.9	36.9
Catawba, SC	6	16.4	21.7
Paint Creek, Scioto, OH	12	13.0	22.4

ticularly during high flow conditions. Since the baskets sit just above the bottom, siltation problems are minimal. Because of its versatility it can be used in deeper water (>1 ft) which might preclude the use of a standard Surber Sampler.

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A HISTORY OF OLIVER LAKE #2, CHIPPEWA COUNTY, WISCONSIN, BASED ON DIATOM OCCURRENCE IN THE SEDIMENTS

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Abstract

A general history of Oliver Lake #2, Chippewa County, Wisconsin, has been constructed. Interpretations were based on a diatom analysis of a vertical profile of bottom sediments taken from the deepest part of the lake using two types of coring devices. Evidence indicates that a shallow, slightly alkaline lake, moderately high in nutrient content, evolved into a relatively deep, highly acidic lake, low in available nutrients. Diatom communities of the most recent sediments indicate these trends may now be reversed.

INTRODUCTION

Techniques of interpreting changes in lakes by analyzing fossil diatom communities of the sediments are well established. Studies by Conger (1939), Andrews (1966), Charlton (1969), Florin and Wright (1969), Florin (1970), Andresen (1976) and Stoermer (1977), in the Great Lakes region; and by Patrick (1954), Round (1957 and 1961), Stockner and Benson (1967), and del Prete and Schofield (1981), elsewhere, are representative. There are many publications available outlining diatom identification which is based on the size, shape, and ornamentation of easily-preserved, glass-like walls. Many species have narrow habitat requirements, being greatly affected by temperature, available nutrients, and chemical properties of the water (Patrick 1948). There is also information available concerning their pH preferences, and even though pH is less indicative of water conditions than factors such as mineral content (Patrick 1945), it is still useful.

This study was based on a single sediment profile. Although relying on a single site increases the probability of taking a sample that does not represent the lake as a whole, there is precedence for doing so (Patrick 1954, Florin 1970, Stoermer 1977). Florin (1970) briefly discusses the problem. By using the deepest, most stable part of the lake, it seems that unnecessary effort can be eliminated while still collecting an adequately representative sample.

Only the prevalent species (relative density > 3%) have been used in the majority of the analyses and interpretations. Patrick (1948) discusses the use of the largest populations as the best interpretive indicators.

Certain problem taxa were encountered but only restricted interpretive use was made of them. In a few instances identification was not possible and these were assigned numbers and recorded as such. By taking a conservative, selective approach, it is believed that the taxonomic and ecological problems have been minimized without excessive loss of information.

STUDY SITE

Oliver Lake #2, in sec 24, T31N, R8W, Chippewa county, Wisconsin, lies on an irregular terrain deposited as stagnant, ice-core moraine, just within the maximum advance of the most recent continental glaciation (Cahow 1976). This dark water, bog-rimmed, acidic (surface pH, 5.1) lake has characteristics that reduce disturbance of the bottom: 1) a small surface area of 1.6 hectares accompanied by a relatively great depth of 21 meters, 2) a wind sheltered location bordered by uplands some 6 to 12 meters above the lake surface, and 3) a bottom oxygen deficit (instrumental determination) in the winter which, as Simola (1977) points out, would eliminate large, bottom crawling animals. Lakes with these characteristics are susceptible to chemical stratification. However, with uniform conductivity throughout the water profile, and a standard, winter inverse temperature stratification, the lake was apparently not meromictic at the time of data collection.

Procedure

A vertical profile of the bottom sediments at the deepest part of the regularly shaped, slightly oblong, bowl-like basin was obtained using two different coring devices. A 195 cm long core of the uppermost sediments was taken through the ice on 5 January 1983 using a freeze-core device (Swain 1973). The upper end of the sample was marked by the clearly visible, water-sediment interface, indicating disturbance of the sediments had been minimal. This core was wrapped in aluminum foil to reduce dessication and transported on dry ice to the laboratory for storage.

On 26 February 1983 a piston-core device (Livingstone 1955) was used through the ice at the same site to remove successively deeper, 1 meter long segments, resulting in an additional 268 cm long composite core. Since 21 meters of water was above the sediment-water interface, a rigid pipe casing, slightly larger in diameter than the piston corer, was used, not only to prevent bending of the sampler thrust rod when pressure was applied to take the sample, but also to ensure that each time the sampler was lowered it entered the same hole in the sediments. Based on a subsequent comparison of diatom communities from this core to the previously-taken freeze-core sample as well as on certain trends which were continuous between the two cores—a declining number of alkaliphilic species, a constant number of acidophilic species, a rising number of *Eunotia* individuals, and constant diversity —the piston core portion began an estimated 250 cm below the water-sediment interface and continued to 500 cm.

A small cork borer was used to take 7 mm diameter by 20 mm long subsamples, spaced 50 cm apart, from the composite profile. Several mm of each end of each plug were discarded to reduce the chance of contamination from other levels. These subsamples were oxidized (van der Werff 1953) before preparing strewn-mounted microscope slides (Patrick and Reimer 1966) with Hyrax (R.I., 1.65) as the mounting medium. A slide from each subsample level was examined at 1250× with a Zeiss research microscope. Randomly selected transects were taken until a minimum of 400 diatom valves were identified and tabulated from each slide. McIntire and Overton (1971) have used information diversity measures for various diatom counts in establishing sample size adequacy for an ecological study of diatoms of similar scope.

Numerous publications were used to identify the diatoms, but those of Patrick and Reimer (1966 and 1975) and of Hustedt (1930 and 1930-66) were the primary sources. Subsamples were labelled (as levels) using their distance, in cm, below the sediment-water interface.

Results

Based on a preliminary visual inspection, only the deepest 30 cm (Level 470 to 500) of the profile had noticeable amounts of inorganic material. Wet mount examinations of this portion at a magnification of 500× before any treatments revealed: 1) both Levels 496 and 490 had small amounts of "sand" (particles $> 7\ \mu m$ diameter) mixed with organic matter, 2) Level 496 had a slightly lower proportion of "sand" than Level 490, 3) Level 480 was "gravel" comprised of sand and pebbles (up to 20 mm diameter) with very little organic matter, and 4) Level 470 was almost entirely a reddish clay ($< 7\ \mu m$ diameter). The 1250× study of subsamples prepared for diatom identification also showed: 1) Level 490 had a very diverse diatom flora devoid of pelagic and terrestrial species, 2) Level 480 had many diatoms and a wide array of species (based only on a cursory inspection), and 3) Level 470 had an insufficient number of diatoms to cven count. All other levels consisted primarily of organic material interspersed with diatom valves and fragments. Figure 1 summarizes these observations.

Twenty eight prevalent species were found in one or more of the 11 sediment levels examined. The relative densities and distribution of these species are shown in figure 2.

Many techniques are available to group data into more interpretable groups. Although the efforts to condense seemed to fail, they were valuable in showing that each sediment level was unique. The following examples are representative.

The degree of association between species was measured using Cole's Index (Cole 1949) with signficance tested by Chi square. Among the 28 prevalent species there were only three significant ($P < .05$) relationships: 1) *Asterionella formosa* Hass. and *Fragilaria pinnata* Ehr. were negatively associated, 2) *Eunotia paludosa* Grun. and *F. pinnata* were negatively associated, and 3) *Eunotia flexuosa* Breb. ex Kutz. and *E. paludosa* were positively associated. A subsequent cluster analysis (Williams and Lambert 1959), which uses a Chi square distance measure, resulted only in one significant ($P < .05$) division—those levels with *F. pinnata* present (the 7 deepest levels) and those with it absent (the 4 shallowest levels).

Bray and Curtis (1957) used a 1-2w/a+b index to objectively measure the degree of dissimilarity between samples. The indices calculated for Oliver Lake #2 were high, indicating high level to level dissimilarity.

Curtis (1959) proposed a ratio of prevalent modal species to prevalent species for detecting hybrid communities. A comparable ratio, disregarding prevalence, could also be used to give more weight to the rare species.

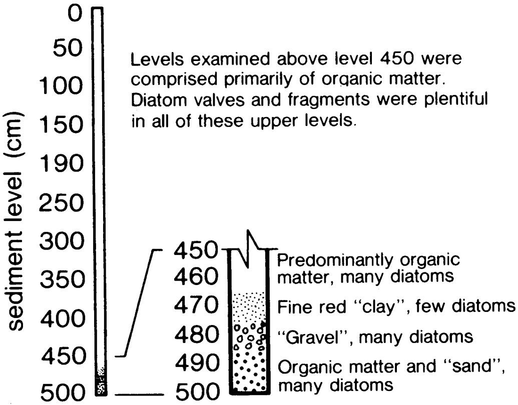

Fig. 1. Characteristics of the bottom 50 cm of the sediment profile taken from Oliver Lake #2. The proportion of "sand" at Level 496 was slightly lower than at Level 490.

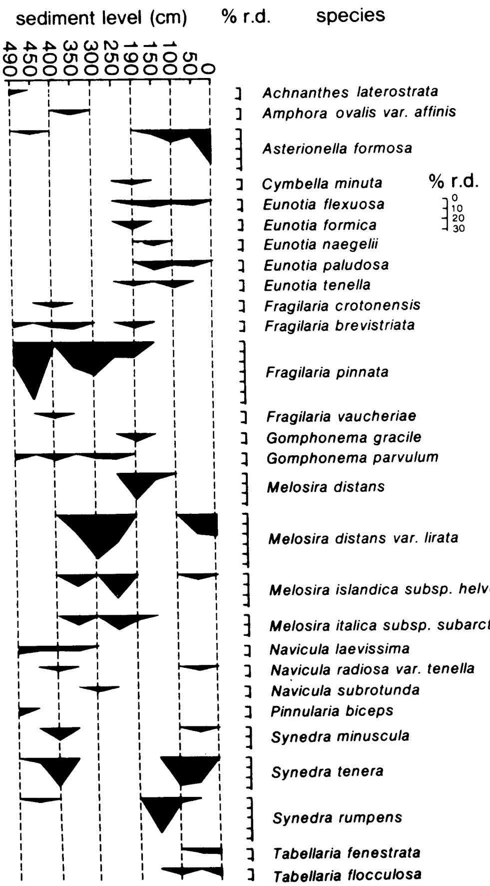

Fig. 2. Percent relative densities of the prevalent fossil diatoms for each sediment level examined from Oliver Lake #2. Relative densities less than 3% are shown as 0.

Low ratios indicate a lack of uniqueness. Figure 3 shows that these two indices are simultaneously low only at Levels 50 and 350.

In effect, the species present at various times in the history of Oliver Lake #2 have varied greatly, with little continuity between adjacent levels. This is not as unusual as it first appears to be. Even in an unchanging environment, the kinds of diatom species can fluctuate greatly while the number of species and the relative sizes of the popula-

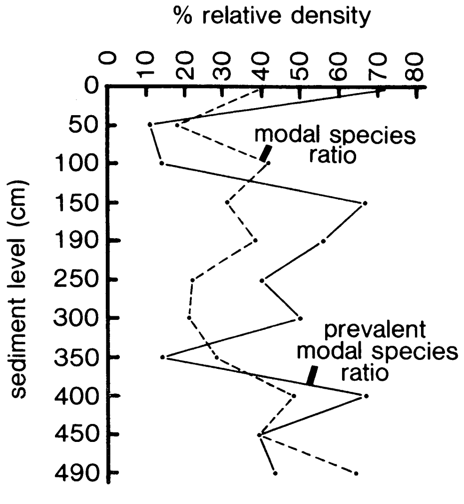

Fig. 3. Modal and prevalent modal species ratios for each sediment level examined from Oliver Lake #2. Low values indicate that the diatom community at that level has a hybrid composition. Only Level 50 and Level 350 have simultaneously low values.

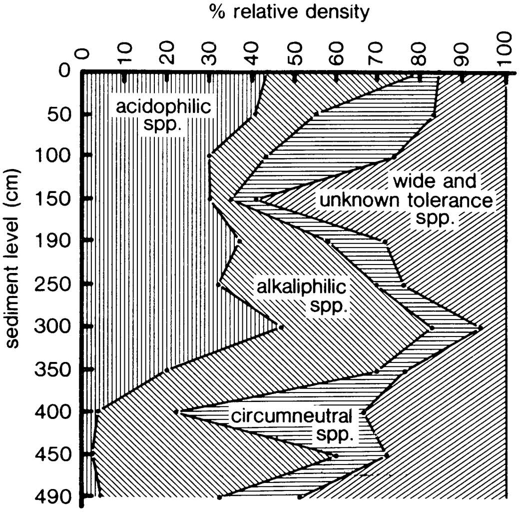

Fig. 5. Distribution of individuals when classified by their pH preferences for each sediment level examined from Oliver Lake #2. Acidophilic: pH preference < 6.5. Alkaliphilic: pH preference > 7.5. Circumneutral: pH preference 6.5 to 7.5.

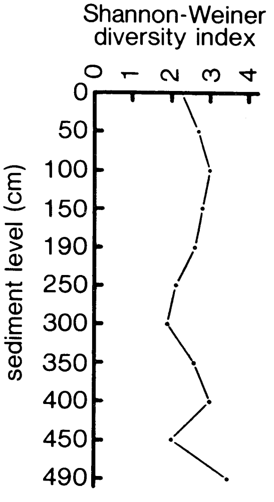

Fig. 4. Shannon-Weiner diversity index for each sediment level examined from Oliver Lake #2. Level to level variation is much greater in the older sediments.

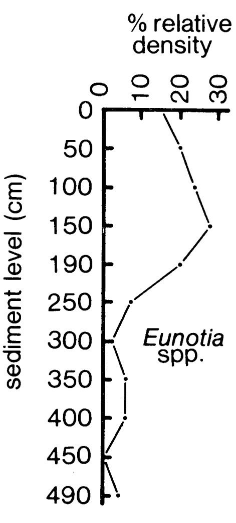

Fig. 6. Percent relative density of the genus *Eunotia* for each sediment level examined from Oliver Lake #2. This genus is much more common in the younger sediments.

tions of the species remain quite constant (Patrick 1962, 1963). There are so many diatom species available that any one of a number of these, in the right place and time, can reproduce rapidly enough to fill niche openings. The Shannon-Weiner diversity index (Shannon and Weiner 1963) uses just these two criteria (number of species and sizes of populations). Remaining constant, it would then indicate relatively stable ecological conditions. As shown in figure 4, the index fluctuates erratically in the earliest stages of lake development but dampens considerably in more recent times.

Species can be grouped by their pH preferences (Foged 1981). As shown in figure 5, acidophilic species are absent from the deepest sediments but become prominent in the more recent sediments. A comparison with fig. 6 shows that the genus *Eunotia* roughly parallels this trend and in fact contributes to it. This would be expected since *Eunotia* taxa are virtually all acidophilic. *Eunotia* genera peak at Level 150. Figure 5 also shows that the combined alkaliphilic-circumneutral pH species are at a minimum at Level 150.

Discussion

Level to level diversity has fluctuated more in the older fossil communities studied than in the recent ones. Since Richardson (1969) has correlated stratigraphic variability to low water levels, this may well mean that Oliver Lake #2 was shallower than at the present. To account for the later stability, a subsequent increase in depth is proposed which provided extra volume to better absorb the effect of factors that influence lake ecosystems. The analyses at each individual level support this contention as well as indicating that conditions became more acidic and more dystrophic.

Level 490 (oldest sediments)

At this time, Oliver Lake #2 was apparently mildly eutrophic. Of the prevalent diatoms, *F. pinnata, Gomphonema parvulum* Kutz and *Fragilaria brevistriata* Grun. are usually found in such water, while only *Pinnularia biceps* Greg. prefers water of low mineral content. The marked lack of acidophilic species indicates somewhat alkaline conditions.

Although shallow water species can exist in deep water if the water is clear enough to allow sufficient light penetration (Conger 1939), only an oligotrophic lake would likely be clear enough. As discussed above, Oliver Lake #2 was apparently mildly eutrophic at this time, so that the abundance of shallow-water species would indeed imply shallow water. Since pelagic species normally abound in deep, mildly eutrophic water, but not in shallow water, their absence here further supports the shallow water proposal.

Diatom diversity is particularly high. Water chemistry apparently had not greatly changed for a long time and an abundance of available niches due to an extended period of favorable habitat development seems probable. However, it is unlikely that the situation was totally static. Maximum diversity may well occur when there is some intermediate disturbance (Huston 1979, van Dam 1982). Presence of some sand at this level further substantiates a somewhat dynamic situation.

It is speculated that the lake at this time was located above a large block of buried glacial ice. Florin and Wright (1969) have proposed the melting of buried ice blocks to be a common means of lake basin formation in glaciated regions. Cahow (1976) felt that most of the lake basins in the area resulted from the melting of buried ice blocks. The gradual deepening of the shallow lake, indicated by the fossil diatom community at this level, to the present day depth of 21 meters, fits well into this buried ice block concept.

Level 480 and 470

These levels were not a part of the diatom analysis, but were included because of their obviously different physical appearance when the entire sediment core was visually inspected. The "gravel" layer of Level 480 would have required a powerful earth-moving force for its transportation to this location. It is conceivable that glacial events—large volumes of swift-flowing water, rafting via chunks of ice, or landslides—provided the impetus. Diatoms in this "gravel" may have been transported from reworked, upstream sites.

On the other hand, subsequent deposition of the easily suspendible clay particles of Level 470 would have required greatly reduced flows. Glacially fed runoff may have been depleted due to recession of the glacier. The insufficient number of diatoms present at this level to even count is consistent with Round's proposal that deposition of clay dramatically reduces diatom populations (Round 1956).

Level 450

Apparently, organic deposition in a shallow lake was renewed. Extensive amounts of the benthic *F. pinnata* and a lack of pelagic species once again indicate shallowness. Sand and clay are no longer present, so that material being transported overland appears to be trapped by some sink surrounding the lake. The establishment of emergent and submergent vegetation at the periphery of the lake may have been that sink. Retarded water movement would cause a dropping of sediment loads before the lake was reached. The organic matter of the sediments would then have come only from production within the lake and from wind-blown sources (e.g. leaf litter).

With acidophilic species still rare, the water was probably somewhat alkaline. Diversity at this level is low and the widely tolerant and benthic *F. pinnata* is very abundant, implying that conditions were harsh for diatom growth. Warm water may have been one of those conditions. Benthic species would have been scarce in a cold, shallow lake (Patrick 1948).

Level 400

An increase in the proportion of circumneutral species, a decrease in alkaliphilic ones, and a concurrent slight rise in acidophilic ones indicate a pH decline. The presence of *Fragilaria crotonensis* Kitton, a pelagic species, would have required some deeper, open water—presumably provided by the sagging of the lake bottom as the buried ice block slowly melted. With *F. crotonensis, F. brevistriata* and *G. parvulum* present, the lake was probably still mildly eutrophic.

Level 350

The lake apparently continued its pH decline. Although alkaliphilic species (*F. pinnata* in particular) still were abundant, acidophilic species such as *Melosira distans* var. *lirata* Ehr. had also become prevalent. Water depth and nutrient content were apparently sufficient to support pelagic species such as *Melosira italica* subsp. *subarctica* O. Mull. and *A. formosa* in small numbers. The lower diversity might be attributed to acidic conditions "weeding out" less tolerant species. A small bog may have developed at the perimeter—not only increasing acidity, but also donating water-darkening humic substances that would be resistant to breakdown in the more acidic conditions.

Level 300

As indicated by the dissimilarity indices and the proportion of modal species, this was a hybrid level, showing some similarities to both Level 350 and Level 250. Acidophilic species peaked here due to the high proportion of *M. distans* var. *lirata*, but the alkaliphilic *F. pinnata* was still present in large numbers. Diversity was low indicating a major transition, presumably from alkaline to acidic water, was taking place.

Level 250

The increase in individuals within the genus *Eunotia* implies that pH had dropped and that dystrophic, bog-like conditions were likely established. Most of the species of *Eunotia* indicate soft, somewhat acid water (Patrick 1977). This has been consistently confirmed, particularly in deep lakes (e.g. Ford 1982). A floating bog that covered shallow water and contributed humic material which would prevent sufficient light for photosynthesis from reaching the bottom, may have caused the decline of benthic species. None of the prevalent species were indicative of eutrophic conditions, implying that nutrient levels were low, possibly due to unavailability in acidic conditions rather than to an absolute deficiency.

Level 190

The relative proportion of *Eunotia* individuals was high and acidophilic species were plentiful. A well developed bog is proposed and the lake was likely dystrophic. High humic content and low available nutrient levels determined the biotic composition. Increased diversity might have been caused by a stable period of dependable resources. A wider array of specialist species could then have gained a competitive advantage, reducing the numbers of the more extensive generalist species (Smith 1980).

Level 150

The high proportion of *Eunotia* individuals and low proportion of alkaliphilic species indicate that by this time Oliver Lake #2 was a prime example of a dystrophic acid-bog lake. Although pH and calcium content of the water may be the most important factors in diatom distribution, proper substrate may have been the primary reason certain attached species were present (Bruno and Lowe 1980). The bog would have provided such a specialized habitat. This could also explain the rarity of benthic species as well as the commonness of littoral ones such as *Synedra rumpens* Kutz. Although *A. formosa* was present, it and other planktonic species were scarce. This could still have been due to a nutrient tie-up under the acidic conditions.

Level 100

The proportion of *Eunotia* individuals declined, but the density of acidophilic individuals had remained constant. Alkaliphilic species were still rare. Although still a dystrophic, acid-bog lake, it appears that bog expansion had stagnated. With the relatively high diversity, water conditions were apparently in a stable phase with only slight disturbance.

Level 50

The proportion of modal species and a low dissimilarity index indicate that this was a hybrid level which resembled Level 100. A surrounding bog continued to provide living space for littoral species such as *Synedra tenera* W. Sm. Hints of new, rather surprising, changes were also found here. The proportion of alkaliphils increased while that of *Eunotia* individuals decreased.

Level 0

The increasing alkaliphil and decreasing *Eunotia* trends became more marked. It becomes tempting to propose that lake acidity was decreasing and the dystrophic, bog-like conditions were being altered. Recent personal observation and instrumental measurements do not support such an interpretation. Oliver Lake #2 is still a highly acidic, dark water, dystrophic lake with low conductivity and depleted winter oxygen supply.

However, the great abundance of *A. formosa* (36.9% r.d.) cannot be totally ignored. There are some variations in the literature concerning its ecological preferences but it is usually considered an alkaliphilic species that is normally best developed in somewhat nutrient-rich water. If these qualities are truly not artifacts, the diatom analysis has been able to detect trends—decreasing acidity and increasing nutrient availability—that were not apparent in the restricted instrumental analyses. These same trends have been found in certain Swedish lakes and have been related to agricular development of the drainage basin (Renberg 1976).

Summary

Immediately following the most recent glaciation, Oliver Lake #2 was apparently a shallow, slightly alkaline, mildly eutrophic lake. As uplands weathered and became vegetated, nutrient inputs were altered. A huge ice block buried beneath the lake slowly melted and a bog developed at the periphery. Several trends became apparent: 1) increasing depth, 2) increasing acidity, 3) increasing dystrophy, and 4) reduced availability of nutrients—so that the lake has become deep, acidic, and dystrophic, with very dark water. However, there are now indications that acidity may be decreasing and nutrient availability rising, possibly as a result of cultural modification of the drainage basin.

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THE AQUATIC MACROPHYTE COMMUNITIES OF TWO STREAMS IN WISCONSIN

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Abstract

The aquatic macrophyte communities of two streams, Black Earth and Lawrence Creeks, were examined using the line intercept method from May through August, 1981. The data were analyzed using multivariate statistics. The seasonal succession of species was significant in both streams. Differences within and between their plant communities were also examined, as well as the distribution of the plant species in relation to environmental factors.

INTRODUCTION

Aquatic macrophytes are an important, but neglected, component of stream communities. Macrophytes contribute a large portion of the energy budget in some streams (Minshall 1978). In addition, they stabilize the stream bed and provide food and shelter for macroinvertebrates and small fish (Dawson 1978; Haslam 1978). In some instances, eutrophication has caused large growths of macrophytes that are deleterious to fish habitat and undesirable for human recreation. For these reasons, a greater understanding of stream macrophytes is necessary to an understanding of stream ecosystems as a whole.

Plants living within the stream ecosystem have to contend with an environment that is entirely different from that of lentic ecosystems. The stream environment is complex and heterogeneous, having many habitat patterns superimposed on each other at varying scales. There is a gradual change in character from the headwaters to the mouth (Vannote *et al.* 1980) with local variation in habitats primarily due to geology, geomorphology and a patchy distribution of microhabitats (Hynes 1975; Dawson, Castellano and Ladle 1978). All of these factors create environmental differences that affect the distribution and abundance of aquatic macrophyte species.

The macrophyte communities of temperate streams respond to a complex array of environmental factors in a definite seasonal pattern as well. During the year, various environmental events in the watershed affect the stream, giving one species a competitive advantage over another. Along with seasonal changes of temperature and photoperiod, seasonal rainfall and intermittent flooding cause dramatic changes in microhabitats, sediment contours, and current regimes. One intense flood may scour a stream so intensely as to effectively remove a large proportion of plant biomass and change the contours of the stream bottom (Bilby 1977; Westlake 1975; Wetzel 1975). Flooding at one stage may remove more propagules of one species than another, or may occur at a time when one species is more susceptible to disturbance than another. Therefore, different species may dominate from one period or year to another (Dawson, Castellano and Ladle 1978; Kimmerer and Allen 1982).

Terrestrial plant ecology has used quantitative methods for many years. These methods have been applied only recently to aquatic systems. Swindale and Curtis (1957) used the quadrat method in developing their index of aquatic plant associations in Wisconsin. Lind and Cottam (1969) used the line intercept method of McGinnies (1952) to quantify the changes in macrophyte composition which resulted from the eutrophication of Lake Mendota, Wisconsin. Lind and Cottam found this method preferable to the quadrat method in measuring aquatic plant cover.

In stream environments, quantitative methods are even less commonly used. Haslam (1978) used presence/absence data in her study of the stream vegetation in England. Other studies which used this method were those of Holmes and Whitton (1977) and Smith (1978). The presence/absence method is adequate for large-scale investigation across many sites, such as in the case of whole riverine systems or provinces, but is not intensive enough for the study of one or two streams. A method for study on a smaller scale has been to measure biomass (Kullberg 1974; Hannan and Dorris 1970), but this method requires much time and a large number of samples due to variability.

We have chosen to measure cover using the line intercept method, for several reasons. First, no problem arises with quadrat size affecting the measure of cover. Second, line intercept is a rapid method that does not require cover estimation (McGinnies 1952). Third, reliance on cover alone avoids the difficulty of counting or estimating the number of individuals. Fourth, with the cross-channel transect we were able to measure vegetation along the entire cross-section of the stream, not just a small segment, as with the quadrat method (Grieg-Smith 1957).

We studied the macrophyte communities of Black Earth and Lawrence Creeks to examine the successional trends within the streams as well as quantitative differences within and between the streams. By measuring environmental data, we correlated these trends to measureable environmental factors.

Materials and Methods

Sites

Black Earth Creek

Black Earth Creek is a class-one trout stream in Dane County (Figure 1). The study area was near the Village of Cross Plains. The average stream gradient is 1.96 m/km, and the stream drains 116.78 km^2 (Dane County Regional Planning Commission DCRPC 1979). The area surrounding Black Earth Creek has a variety of land uses. Most of the land directly along the banks is in a public fishing easement, fenced off to maintain the streambank. In many places, arboreal vegetation has returned. The drainage basin as a whole is mostly agricultural, with 38% in pasture and 15% cultivated. The remainder is largely composed of wetlands (DCRPC 1979).

The average yearly water flow for Black Earth Creek is 0.879 m^3/s; however, this is not evenly distributed over the year (USGS

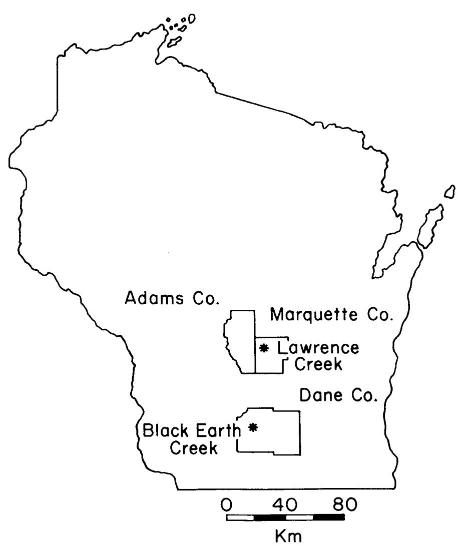

Fig. 1. Location of Black Earth and Lawrence Creeks within the State of Wisconsin.

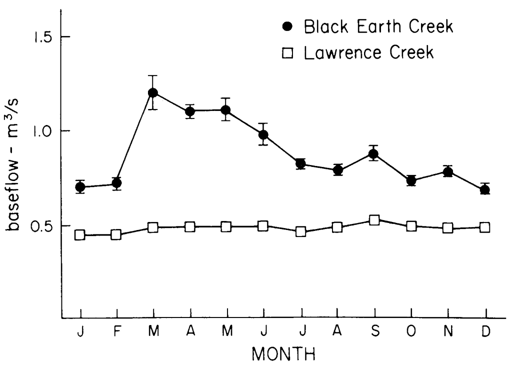

Fig. 2. Water flow for Black Earth and Lawrence Creeks (data from USGS). Bars indicate ± standard deviation; standard deviation smaller than square for Lawrence Creek data.

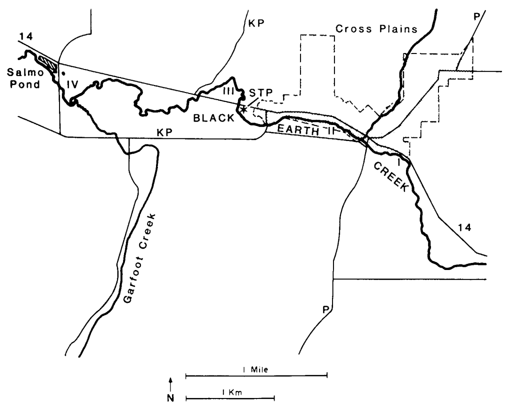

Fig. 3. Map of study sections on Black Earth Creek. Roman numerals indicate section numbers.

1973b; Figure 2). Flow is low in early winter when precipitation is low and in a solid form (snow or frozen rain). Black Earth Creek has a tendency to flood in late winter or early spring (DCRPC 1979). The average flow is also highest during this period. Flow generally decreases over the summer, probably due to increased transpiration and flow resistance caused by plants. However, in August of the sampling year, heavy rains caused a spate with a maximum flow of 3.059 m^3/s on 27 August 1981 and 4.816 m^3/s on 1 September 1981 (U.S. Geological Survey (USGS), personal communication, 1981). Although Black Earth Creek receives a base flow of artesian spring water and ground water, high flows commonly occur from heavy surface runoff of adjacent agricultural land.

Black Earth Creek is a "rich" limestone stream. High concentrations of nutrients support high productivity of plants and other aquatic organisms (Brynildson and Mason 1975). This is largely due to the parent limestone material surrounding the stream, which provides a needed high inorganic carbon source for high primary productivity. A moderately high amount of suspended solids is present. The major pollution problems are coliform bacteria and phosphorus, due to both surrounding agriculture and the sewerage plant (DCRPC 1980).

The stream flows through a variety of land use categories in the four study sections (Figure 3). Above County Highway (CTH) P, Section I, it flows through a wetland area. Section II, below CTH P, flows through a city park area behind the Village of Cross Plains. It then passes a light industrial area and the Cross Plains sewerage treatment plant. Section III, the "horseshoe," flows through a residential area in the lower half. Section IV flows through agricultural fields and pastures. Along most of its length in II through IV, the Wisconsin Department of Natural Resources (WDNR) has a streambank easement where trees, mostly cottonwood and willow, have grown back, along with some planted red cedar.

Lawrence Creek

Lawrence Creek is a class-one trout stream located in western Marquette and eastern Adams counties near Westfield (Figure 1). Most of the 6.5 km stream and a significant portion of its 16.4 km^2 drainage basin lie within the 338 ha Lawrence Creek Public Hunting and Fishing Area (Hunt 1966). The basin is predominantly wooded with red oak forests and several pine plantations. Cattail and sedge marshes lie along the stream

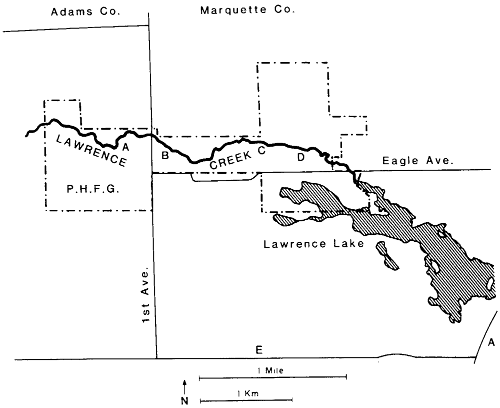

Fig. 4. Map of study sections on Lawrence Creek. Letters indicate sections.

course. This gives the basin the characteristics of a forested watershed. The runoff and groundwater lack significant anthropogenic inputs.

The yearly water flow for Lawrence Creek is regular, varying slightly throughout the year (Figure 2). Largely due to its forested watershed and the high percentage of groundwater and springs that constitute its flow, it is not subject to flooding (USGS 1973a). The annual average flow is 0.473 m^3/s. The elevation drop is about 8.8 m for an average slope of 1.62 m/km.

Lawrence Creek is also divided into four sections (Figure 4). The upper section, A, is characteristic of headwater streams with shallow depths, a few riffles and a predominantly gravel substrate. It is largely surrounded by forested land. Section B is much slower and deeper, but also has a significant amount of gravel. It flows through a marsh. Section C and D also flow through marshes, but differ in having an almost total absence of gravel. The predominantly sand substrate greatly influences the character of the lower portion of the stream.

Field Methods

Each of the streams was divided into four arbitrarily determined study sections approximately 1 km in length (as discussed above). Once per month (May through August 1981) we sampled 20 transects in each section. The transect site was selected using a stratified-random system. At each site we measured the following environmental data: width, water temperature, light extinction, canopy and substrate. The transect was constructed with a plastic-coated wire clothesline (Lind and Cottam 1969) with 1 dm and 1 m graduations indicated. Width was determined using the transect. In the middle of each 1 m interval, depth and current were measured. Depth was measured with a meter stick. Current was measured using an orange as a float for a distance of one meter following the method of Hynes (1970). Water temperature was recorded with a Yellow Springs Instruments thermistor-thermometer #44. Light (photosynthetically active radiation, or PAR) was measured with a Lambda quantum sensor 3LI-17Q and submersible probe; and light extinction was calculated using an equation from Nichols (1971; Hutchinson 1957). Canopy, although part of the terrestrial biotic community, is most conveniently considered with the physical environment. Canopy was estimated as the total percentage of overhead tree or shrub cover to the nearest 10%. The substrate type for the site was classified as either gravel, sand or silt.

The transect was also used to measure the cover of plant species as points of line interception. Each species that was present under a 1 dm segment was considered to "cover" that 1 dm segment. In addition to percent cover, relative cover was calculated to assess plant species composition. Relative cover is calculated by dividing the percent cover of a species by the sum of cover for all species, or

$$\text{relative cover} = \frac{X_i}{\sum_{i=1}^{n} X_i} \times 100$$

where X_i is the cover for species i and n the total number of species. Relative cover indicates the percentage of the plant community represented by an individual species, and so the sum of relative cover for all species is 100. Relative cover is a measure of dominance in the plant community.

Species identification was based initially on Fassett (1957), although taxonomic names were used after Gleason and Cronquist (1963). Voss (1972) was especially helpful in identifying species of *Potamogeton.*

The U. S. Geological Survey (USGS) provided water flow data for Lawrence and Black Earth Creeks from October, 1967 to September, 1973 (1973a,b). Water flow data for this six year period was averaged for each stream to indicate mean base flow, as shown in Figure 2.

Water chemistry data for Black Earth Creek came from two reports by the Dane County Regional Planning commission (DCRPC 1979; 1980). Water quality data from Hunt (1966) and Mason (unpublished) were used for Lawrence Creek.

SEDIMENT SAMPLES

In July, five sediment samples were taken from each section of both streams. Sample sites were determined using a stratified-random sampling procedure. The sample was obtained from the thalweg of the stream course using an Eckman dredge. The sediment samples were transported in polyethylene bags to the laboratory where they were refrigerated in polyethylene containers with sealing tops. Particle Size Analysis was performed using the Bouyoukos Hydrometer method (Foth 1978; Love, Corey and Gilmour 1977). The U. S. Department of Agriculture (USDA) system of particle classes was used (Foth 1978).

Crucibles for analysis of organic and $CaCO_3$ content were first heated to 950 C for 24 hours and then cooled under dessication for taring. Dry weight, organic matter, and $CaCO_3$ were determined using the Thermolyne muffle furnace F-A1740 after Wetzel (1970) and Adams, Guilizzoni and Adams (1978b) on wet samples from 50 to 100 grams. Organic matter composition was determined by combustion at 550 C, as compared to oven dry weight (105 C). Percent $CaCO_3$ was measured by conversion of CO_2 lost at 950 C to % $CaCO_3$ present in the sample (Adams, Guillizzoni and Adams 1978b).

STATISTICAL ANALYSES

Average cover values were entered along with environmental data for 600 transects in

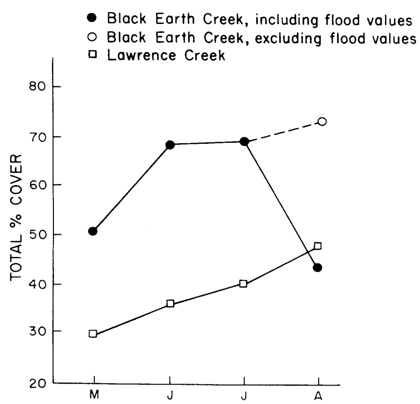

Fig. 5. Total percent cover of macrophytes for Black Earth and Lawrence Creeks over the growing season (M, May; J, June; J, July; A, August).

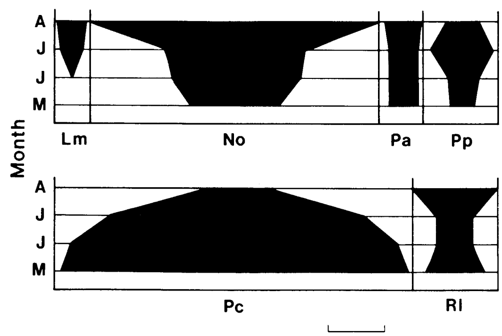

Fig. 6. Seasonal succession as indicated by relative cover for Black Earth Creek (Lm, *Lemna minor;* No, *Nasturtium officinale;* Pa, *Phalaris arundinacea;* Pc, *Potamogeton crispus;* Pp, *Potamogeton pectinatus;* Rl, *Ranunculus longirostris;* M, May; J, June; J, July; A, August).

order to perform statistical analyses on a Sperry-Univac 1100 at the University of Wisconsin-Madison Academic Computing Center (MACC). Descriptive statistics were computed for each section and sampling period. Descriptive statistics, one-way analysis of variance (ANOVA) and Discriminant Analysis were performed using the Statistical Package for the Social Sciences (SPSS; Nie *et al.* 1975). Discriminant Analysis was also performed using the BMDP Statistical Package (BMDP; Dixon *et al.* 1981).

Analyses for seasonal succession were performed by grouping the data from all sections for each month. Differences between sections were examined by grouping data for all months for each section. Therefore, each month or each section has data for eighty transects, which is an adequate sample size for these analyses. Examination of the differences between the two streams used all data for each stream, or the data for 320 transects.

Results and Discussion

Succession

Black Earth Creek

The total cover of Black Earth Creek increases rapidly from May to June (Figure 5).

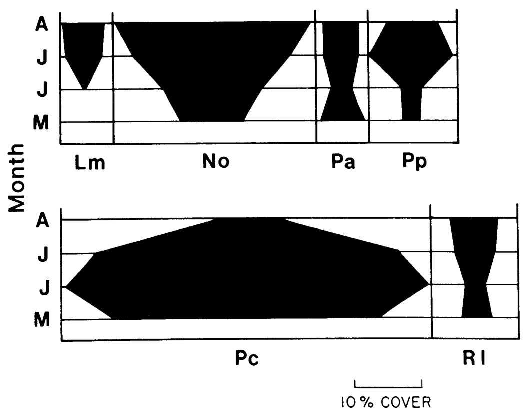

Fig. 7. Seasonal succession as indicated by percent cover for Black Earth Creek (Lm, *Lemna minor;* No, *Nasturtium officinale;* Pa, *Phalaris arundinacea;* Pc, *Potamogeton crispus;* Pp, *Potamogeton pectinatus,* Rl, *Ranunculus longirostris;* M, May; J, June; J, July; A, August).

By June, total cover peaks and senescence of *Potamogeton crispus* begins (Figure 6). Due to a large amount of rain over a two week period, a large flood occurred on Black Earth Creek in August after sampling sections I and II, but before sampling sections III and IV. This flood greatly reduced total cover, leaving vegetation only along the banks and a few protected sites. The data for Black Earth Creek are presented both including and excluding values affected by the flood.

Potamogeton crispus has its highest relative cover in May when it is nearly full grown due to overwinter growth (Figure 6; Haslam 1978). Dominance continues through June, when *P. crispus* literally fills many stretches of the stream from bank to bank. In June *P. crispus* senesces, with large mats of it floating downstream and lodging around obstructions. Although cover is still fairly high, biomass was observed to be down significantly by July. A sparse, though continuous, cover of *P. crispus* is then maintained through the rest of the summer. However, the flood removed most of the stems remaining, explaining the sudden decrease in cover in the lower two sections.

Nasturtium officinale increases steadily in cover throughout the summer. Its high relative cover for August is due to the absence of other vegetation after the flood (Figure 7). The flood apparently did not affect *N. officinale* due to its protected streambank habitat.

Phalaris arundinacea is fairly constant in relative cover throughout the summer, starting growth early from rhizomes. The flood did not affect it due to its stable gravel and stream bank habitats.

Potamogeton pectinatus increases in dominance after the senescence of *P. crispus,* apparently replacing it. However, the flood in August removed this species also from the lower stretches of the stream.

Ranunculus longirostris steadily increases in cover throughout the summer. Being tolerant of spates, it is second in importance to

N. officinale for August. Its dominance in May is due to overwintering evergreen stems.

Lemna minor appears later in the summer, probably due to its need for warm waters to initiate vegetative reproduction.

For most temperate stream communities, several species share dominance over the season as environmental conditions change in the stream. In this respect, the phenology of *P. crispus* shows an interesting ecological adaptation. Turions germinate in late autumn, with growth occuring all winter. Maximum development is achieved in late spring, with flowering and fruit formation in late May or in June. Turions then develop on the stems or rhizome during this period and are dormant until autumn, and the majority of the above-ground biomass senesces. Dormancy is broken by cold temperatures (Sastroutomo 1981). *Potamogeton crispus* is adapted to grow rapidly in early spring to compete with other species in a eutrophic environment. It then dies off in midsummer, allowing other species to grow, especially *N. officinale* and *P. pectinatus.* However, the flood in August removed most of the plants in the mid-stream area, especially the remaining *P. crispus* and *P. pectinatus.* This left the streambank macrophytes *(Nasturtium* and *Phalaris)* and the more spate-tolerant vegetation, such as *Ranunculus,* to dominate. Such floods are fairly common on Black Earth Creek, and are an important factor in plant distribution. The seasonal succession of species in Black Earth Creek was highly significant (at the $p = 0.01$ level) as determined by Discriminant Analysis, with significant changes occuring in *Lemna, Nasturtium, P. crispus,* and *P. pectinatus.*

Lawrence Creek

The total cover for Lawrence Creek increases regularly throughout the summer, as expected in a situation without disturbance (Figure 5). However, the underlying change in species is more complex. *Elodea canadensis* and *Nasturtium officinale* have overwintering stems that allow rapid growth in the spring. *Elodea* is the dominant species for all but the month of May, when *P. pectinatus* is more common due to its early phenology. *Elodea canadensis* grows rapidly from overwintering stems (Figure 8). Cover values increase throughout the summer, but relative cover decreases due to increased emergence of other species (Figure 9).

High overwintering cover of *Nasturtium officinale* allows it to have high relative

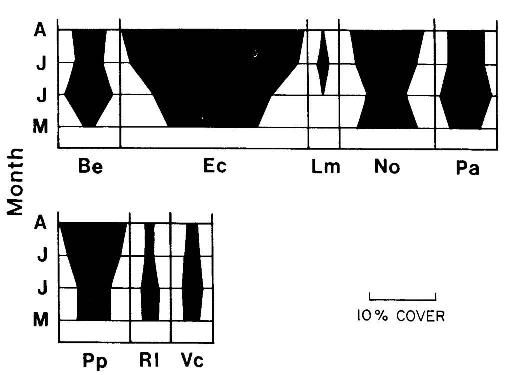

Fig. 8. Seasonal succession as indicated by percent cover for Lawrence Creek (Be, *Berula erecta;* Ec, *Elodea canadensis;* Lm, *Lemna minor;* No. *Nasturtium officinale;* Pa, *Phalaris arundinacea;* Pp, *Potamogeton pectinatus;* Rl, *Ranunculus longirostris;* Vc, *Veronica catenata;* M, May; J, June; J, July; A, August).

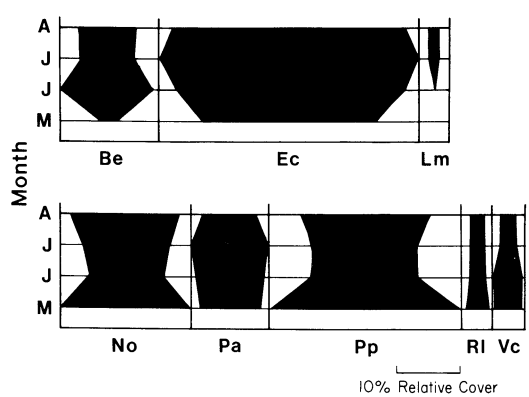

Fig. 9. Seasonal succession as indicated by relative cover for Lawrence Creek (Be, *Berula erecta;* Ec, *Elodea canadensis;* Lm, *Lemna minor;* No, *Nasturtium officinale;* Pa, *Phalaris arundinacea;* Pp, *Potamogeton pectinatus;* Rl, *Ranunculus longirostris;* Vc, *Veronica catenata;* M, May; J, June; J, July; A, August).

cover due to the relative scarcity of other species. Percent cover increases throughout the summer, with an increase in dominance. *Potamogeton pectinatus* has high relative cover compared to percent cover due to wide distribution and occurrence where other species are lacking. The cover values of *Phalaris arundinacea* are slightly affected by man. One section was mowed in July, removing some of the cover. However, flowering and seed set also occur at this time, with ensuing senescence reducing cover (Sculthorpe 1967).

Berula erecta grows from underground rhizomes during late May and early June. *Veronica catenata* and *Ranunculus longirostris* also have an early period of outgrowth. *Lemna minor* is late in appearing, and at low levels due to the fast current of this stream. Few refugia exist for the growth of *Lemna minor* in Lawrence Creek, such as backwaters and slow-moving pools.

For Lawrence Creek, relative cover is high in early spring for those plants with high overwintering cover and rapid growth from dormant perennial parts. This is especially true of *Elodea canadensis, Nasturtium officinale,* and *Potamogeton pectinatus.* These three plants are dominant throughout the year. Discriminant Analysis found seasonal differences, to be highly significant, with *B. erecta, E. canadensis, L. minor,* and *P. pectinatus* to be significant elements in this seasonal change (at the $p = 0.01$ level). Late in summer or early autumn, most of the plant biomass senesces, returning to low overwintering levels. Limited waterflow records for Lawrence Creek seem to indicate that spates are extremely infrequent and are therefore less important in plant community regulation than observed in Black Earth Creek.

Temperate stream communities tend to exhibit a cyclic relationship between cold and warm temperature plants. Several species dominate during the winter and early spring due to a tolerance of colder water and/or lower light regimes (e.g., *N. officinale* and *E. candensis*). As spring and summer progress, total cover and diversity of macrophytes increase. After this period of growth, plants begin to senesce. *Potamogeton crispus* senesces early in the summer, allowing other species to replace it. As winter approaches, there is rapid senescence of the remaining species. Although a few plants remain intact throughout the winter, most are protected in dormant vegetative propagules. Some propagules, such as tubers, roots, and rhizomes, may be under the sediment; others are above the sediment, as in the case of turions and hibernaculae. Such structures allow rapid germination for the next growing season. The actual pattern found in the plant community depends on environmental factors affecting the watershed. Some factors, such as flooding, may be randomly occuring historical events. In some streams, such as Lawrence Creek, the watershed has few floods so that this factor is of little importance to the plant community. In others, such as Black Earth Creek, occasional floods alter species pattern and result in different dominant species than in non-flood years.

INTRASTREAM DIFFERENCES

Physical Environment

Black Earth Creek

The sediment of Black Earth Creek is largely gravel mixed with silty alluvium. The highest proportions of gravel and sand occur in II and III (Table 1), the areas with higher current velocity. The largest silt deposits occur in I and IV, the areas of lower current velocity. All sections are high in organic matter and $CaCO_3$. The $CaCO_3$ may be from three causes: silt material, marl ($CaCO_3$) formation on plants in the stream, or gravel material of limestone origin. The latter appears to be the major cause, as the highest percentages of $CaCO_3$ appear in samples with a high percentage of gravel. In general, the appearance of these substrates in I and IV are a covering of silt over a gravel or sand substrate. Riffles are commonly free of silt.

The water temperature of the headwaters

TABLE 1. Sediment composition of each section and stream averages for Black Earth and Lawrence Creeks.

Stream Section	*% Gravel*	*% Sand*	*% Silt*	*% Clay*	*% O.M.*	*% $CaCO_3$*
Black Earth Creek						
Ave.	17.9	66.0	24.8	9.2	9.2	21.0
I	12.0	52.7	30.9	12.1	12.3	12.4
II	30.3	74.5	16.6	8.9	2.7	24.0
III	29.2	73.2	20.4	6.4	7.0	31.4
IV	0.0	59.1	31.3	9.6	14.8	15.8
Lawrence Creek						
Ave.	0.8	97.5	1.4	1.4	0.5	0.6
A	0.7	97.3	1.2	1.5	0.5	0.6
B	0.0	97.7	0.9	1.4	0.4	0.6
C	0.0	97.7	1.1	1.2	0.4	0.7
D	0.0	97.2	1.3	1.5	0.6	0.6

TABLE 2. Environmental data for stream sections and averages for each stream, including standard error (S.E.), for Black Earth and Lawrence Creeks.

Section	*Water Temp (C)*	*Canopy %*	*Light Extinc*	*Depth (m)*	*Current (m/s)*
BLACK EARTH CREEK					
I	12.2	15.5	1.4	0.52	0.12
(S.E.)	0.53	4.0	0.24	0.02	0.01
II	12.1	18.9	1.34	0.32	0.23
(S.E.)	0.38	4.2	0.11	0.01	0.01
III	13.5	59.2	1.81	0.40	0.25
(S.E.)	0.54	4.6	—	0.01	0.01
IV	16.2	20.5	2.56	0.45	0.20
(S.E.)	0.45	3.8	0.29	0.02	0.01
AVERAGE	13.5	28.7	1.88	0.42	0.20
(S.E.)	0.29	2.3	—	0.01	0.01
LAWRENCE CREEK					
A	12.8	10.1	1.15	0.45	0.25
(S.E.)	0.34	3.0	0.19	0.02	0.01
B	12.8	4.74	1.95	0.51	0.22
(S.E.)	0.31	2.2	0.18	0.02	0.01
C	15.8	3.6	1.24	0.35	0.26
(S.E.)	0.39	1.4	0.21	0.01	0.01
D	13.0	9.6	1.29	0.39	0.26
(S.E.)	0.40	2.9	0.33	0.01	0.01
AVERAGE	13.5	7.0	1.37	0.43	0.25
(S.E.)	0.22	1.2	0.12	0.01	0.01

region is low and fairly constant, with progressive warming below the sewerage plant in III and IV. Water temperature in IV is statistically different from that of sections I and II (Table 2, DCRPC 1979).

Section III has a significantly higher overhead canopy of trees than the other sections, according to a one-way ANOVA (Table 2).

The current velocity in I and IV is less than in II and III. No significant difference exists between II and III at the $p = 0.05$ level (Table 2).

Lawrence Creek

The sediment of Lawrence Creek is composed largely of sand (Table 1), due to its parent material, Potsdam sandstone. The sediment is low in both organic matter and $CaCO_3$. The lower sections of Lawrence Creek, C and D, lack any gravel beds and are mostly sandy and sinuous in character. The upper two sections, A and B, have large areas of gravel (Hunt 1977; Table 1; Figure 4).

In a section-by-section comparison, C, being more shallow, had a much higher average water temperature. Continuous influx of ground water and increased water depth led to a temperature decrease farther downstream. (Table 2).

Since most of the stream is bordered by marshy vegetation, the canopy over Lawrence Creek is quite sparse (Table 2). This allows a great deal of light to reach the stream.

The current velocity in B is significantly lower than in C and D. The average depth of B may explain this difference (Table 2).

VEGETATION

Black Earth Creek

The graph of total cover for each section shows that macrophyte cover is much higher in I and IV than in II and III (Figure 10). The major environmental difference between these sections are the siltier substrates in I and IV (Table 1). Both Kullberg (1974) and Hannan and Dorris (1970) report that macrophyte production is much higher on silty substrates than gravel or sand, within a given stream system. Silty sediments absorb more nutrients, especially phosphorus, that are then available for plants. Higher levels of available nutrients may therefore encourage macrophyte growth in these types of sediments (Barko and Smart 1980; 1981).

Potamogeton crispus is the dominant species in all but the upper section. The relative

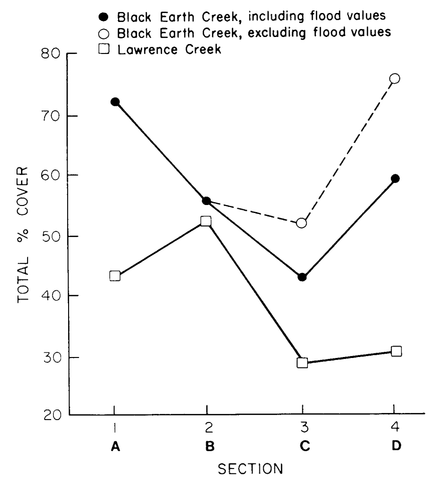

Fig. 10. Total cover of sections of Black Earth and Lawrence Creeks.

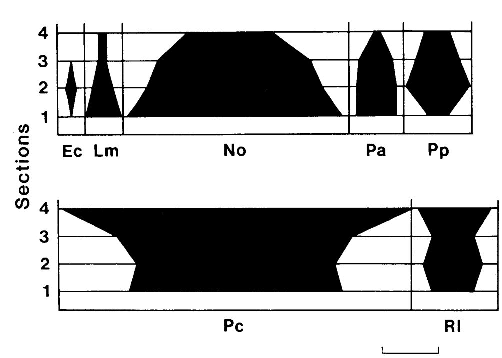

Fig. 11. Relative cover of species for sections in Black Earth Creek (Ec, *Elodea canadensis;* Lm, Lemna minor; No, *Nasturtium officinale;* Pa, *Phalaris arundinacea;* Pc, *Potamogeton crispus;* Pp, *Potamogeton pectinatus;* Rl, *Ranunculus longirostris*).

cover of *P. crispus* decreased in II and III, due to higher current and increased gravel. The increase in relative cover for IV corresponds to the increased silt (Figure 11). The environment of Black Earth Creek is ideally suited to *P. crispus:* a small layer of silt over a layer of gravel or hardened limestone (Haslam 1978), with areas of overhead shade and moderate turbidity.

The relative cover of *Nasturtium officinale* in each section corresponds inversely to the width of the stream. This downstream decrease in the dominance of *N. officinale* may also be related to shade, increased pollution, and increased water temperature (Figure 11, Table 2).

The relative cover of *Potamogeton pectinatus* is directly related to the amount of sand in the substrate (Figure 11, Table 1). Sand is a difficult medium in which to root and remain, and *P. pectinatus* is better adapted to this substrate than the other macrophytes.

Ranunculus longirostris is common in the upper two sections, being found in the gravel areas. The relative cover decreases in the lower sections, possibly from pollution (Figure 11). The increase in dominance in IV is due to its survival of the August spate.

Phalaris arundinacea is fairly common in the upper three sections, growing out into shallow gravel runs (Figure 11). This habitat disappears almost entirely in IV, explaining the absence of *P. arundinacea.*

Lemna minor is found in sheltered areas throughout the stream but is most common in the upper two sections (Figure 11). In I, many water areas occur in which *L. minor* can reproduce. This upstream sanctuary provides a continuous supply of *L. minor* to the lower sections, explaining the relatively high concentration in II.

Elodea canadensis was found exclusively in II, probably due to the silt substrate without the pollution of the lower sections. This section is mesotrophic, with an environment most similar to that of Lawrence Creek. This similarity may explain why both *Elodea* and *V. catenata* were found in only this section of Black Earth Creek.

In summary, the dominant cover of *P. crispus* is directly related to a silty substrate and increased width. *Nasturtium officinale* decreases in cover as the width of the stream increases. Discriminant Analysis shows this sectional difference to be significant at the $p = 0.05$ level, with *Lemna, Nasturtium, Phalaris, Potamogeton crispus, P. pectina-*

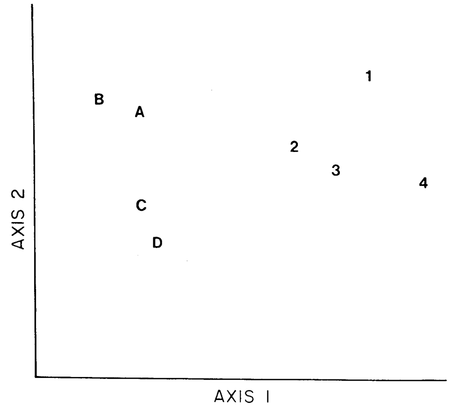

Fig. 12. Discriminant Analysis plot for sections of Black Earth and Lawrence Creeks as based on vegetation composition (numbers-sections of Black Earth Creek; letters-sections of Lawrence Creek).

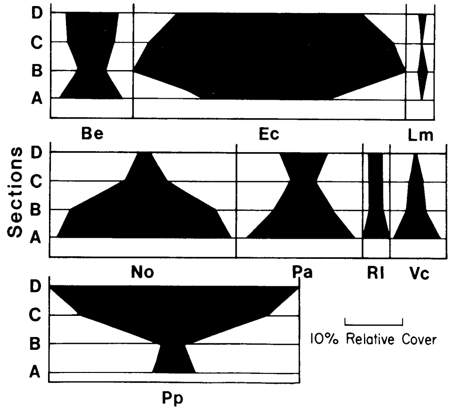

Fig. 13. Relative cover of species for sections of Lawrence Creek (Be, *Berula erecta;* Ec, *Elodea canadensis;* Lm, *Lemna minor; No, Nasturtium officinale;* Pa, *Phalaris arundinacea;* Pp, *Potamogeton pectinatus;* Rl, *Ranunculus longirostris;* Vc, *Veronica catenata*).

tus and *Ranunculus* being a significant part of this difference (Figure 12).

Lawrence Creek

When inspecting Lawrence Creek, it is immediately obvious that the lower sections (C and D) are quite different from the upper ones (A and B). A graph of total macrophyte cover shows that the lower sections have significantly less cover than the upper sections (Figure 10). This is due to a combination of less stable sandy substrate, shallower depths (which bring vegetation in contact with faster current, as the area of highest current velocity is near the surface), and unsupported banks (Haslam 1978; Kullberg 1974). These factors allow the channel to wander, providing poor conditions from macrophyte establishment and growth. Many species cannot root in this unstable environment.

In relative cover for each section (Figure 13), *N. officinale, P. arundinacea,* and *E. canadensis* are the three most important species for A and B (N. officinale dominant in A, *E. canadensis* in B); whereas *B. erecta, E. canadensis,* and *P. pectinatus* are the three most important species in C and D (*E. canadensis* dominant in C, *P. pectinatus* in D).

The dominance of *N. officinale* in section A is due to cold water from many springs and proportionately more bank habitat required for growth (Figure 13). This area is narrow, with bank-type vegetation predominating (e.g., *N. officinale, B. erecta,* and *P. arundinacea*). *Nasturtium officinale* is unable to root adequately in the unstable substrate of the lower sections.

The importance of *Phalaris* is inversely related to the width of the stream (Figure 13, Table 2). As it only invades the stream by vegetative growth from the banks, it should decrease in importance with increased stream width. It is also unable to root in the sand of the lower sections and is relinquished to the more stable banks.

Elodea is common in the quiet, deep pools of A and B (Figure 13, Table 2). As this habitat is more common in B, it is dominant here. Its cover is sharply reduced in section C. However, *Elodea* is still a dominant in C due to the low total cover of all species.

Berula erecta decreases in importance from A to B, presumably for the same reason as *N. officinale.* However, it increases again in the lower sections due to the open habitat with a sandy substrate (Figure 13; Haslam 1978).

Ranunculus longirostris and *Veronica catenata* do best in A, where the highest current and proportion of gravel occur (Figure 13, Table 1). Personal observations of these species indicate that they tend to occur together in this type of habitat and thrive best under these conditions. However, they are represented in the other sections in isolated areas of higher current velocities and stable substrates, such as submerged logs or large rocks.

Potamogeton pectinatus is infrequent in the upper stretches but is a dominant species in the lower sections (Figure 13). It is the only plant that is able to grow in the middle of the shallow sandy channels in these lower sections, where growth is extremely sparse. This macrophyte is probably a case of being the only species "available" to fill this habitat, as is often the case with macrophytes: their distribution may be limited (Haslam 1978).

Several less important species occur in Lawrence Creek, and two deserve special comment. *Lemna minor* was found along the whole stream, but in small quantities. It requires still waters. However, a continuous source of *L. minor* comes from the marshes surrounding the stream. A *Potamogeton richardsonii* colony existed in one 100 m area of section D, which could represent either a new introduction or a remnant of a large population. Haslam (1978) indicates that this species grows in silty areas of rocky streams. This colony was attached to several contiguous submerged logs and silt beds adjacent to the bank.

In summary, the most remarkable aspect of the vegetation of the stream is a pronounced shift from *N. officinale* as a dominant in the upper sections (A and B) to *P. pectinatus* in the lower two sections. The shift in dominance is due to the unstable nature of the sediment in the lower sections where *N. officinale* cannot root. *Potamogeton pectinatus,* however, cannot coexist in the upper sections with those plants which have lower nutrient requirements. *Elodea canadensis* is common throughout the stream and is predominant in the slower, deeper section B. A Discriminant Analysis between sections A through D showed a highly significant difference between the sections based upon all of the major species, with the exception of *Lemna minor.* In this analysis, A and B were similar and grouped as significantly different from sections C and D (Figure 12).

The community compositions of contiguous sections within the two streams were significantly different in most cases. These differences correlated well with changes in environmental factors, such as sediment type, depth and current. In Lawrence Creek a shift from a dominance of *Nasturtium, Phalaris,* and *Elodea* in the upper two sections to *Elodea* and *P. pectinatus* in the lower sections correlated with a shift to shallow, sandy and sinuous conditions in the lower sections. For Black Earth Creek, *Nasturtium* decreased with an increase in water temperature and width. Habitat types for each species derived from this study compared favorably with those observed by other authors.

Environmental Amplitude of Macrophyte Species

As a result of the extensive amount of data collected in this study, it is possible to obtain a quantitative evaluation of the optimal en-

TABLE 3. Relationship of species with environment. 0: no observed relationship −: negative relationship, +: positive relationship, numbers indicate optimal value or limits.

Species	*Width (m)*	*Water Temp (C)*	*Canopy %*	*Substr.*	*Light Extinc.*	*Depth (m)*	*Current (m/s)*
Berula erecta	−	0	0	gravel	0	0	+ .25
Elodea canadensis	0	0	−	sand, silt	turbid 1.40	+ .50	− <.20
Lemna minor	0	+ >15.00	− 0.0	0	0	+ >.40	− <.10
Nasturtium officinale	− <4.5	−	0	0	− 1.25	0	− <.20
Phalaris arundinacea	0	0	− <30.0	gravel	− 1.25	− <.30	0
Potamogeton crispus	0	0	0	silt on gravel	+ 1.80	+ .50	− <.30
Potamogeton pectinatus	0	0	0	silt, sand	+ 1.80	+ .50	− <.30
Ranunculus longirostris	− <4.0	0	0	gravel	0	− <.30	+ >.30
Veronica catenata	− <4.0	0	− <30	gravel	0	− <.30	+ >.40

vironment for each of the species (Table 3). Ideally, these optima should be constant wherever the species is found. However, the plant responds to such a large range of variables that it is difficult to be entirely sure which factor is limiting or encouraging success. For each species we will compare optima from the literature (Table 4) with those derived from our data (Table 3). References used were Fassett (1957), Gleason and Cronquist (1963), Haslam (1978), and Sculthorpe (1967). A full list of macrophyte species found in the two streams is given in appendices I and II. A complete discussion of these species can be found in Madsen (1982).

Berula erecta was not found in the sandy substrates discussed in the literature due to the extreme instability of this substrate in Lawrence Creek. Other discrepancies occur with turbidity and depth.

Elodea candensis is found in sandier substrates than that mentioned in the literature, due to the sandy nature of Lawrence Creek. *Elodea* was also found under a broader range of turbidity in Lawrence Creek because it was found in marshy areas of the stream that produce high amounts of organic matter.

The distribution of *Lemna minor* was consistent with the literature, considering that increased depth is usually associated with slower currents. *Nasturtium officinale* is also consistent in distribution with literature reports. *Nasturtium officinale* is most commonly associated with cold spring waters; therefore, it is associated with smaller tributaries.

Phalaris arundinacea was only found in the stream in fast, shallow areas with gravel substrates or along the banks. This differs from literature reports.

Potamogeton crispus is shade and turbidity tolerant. The optimal substrate is silt over a gravel or hard substrate. *Potamogeton*

TABLE 4. Relationship of species with environment, as determined from literature review. 0 = no observed relationship; − negative relationship; + positive relationship.

Species	*Width (m)*	*Water Temp (C)*	*Canopy %*	*Substr.*	*Turbidity*	*Depth*	*Current*
Berula erecta	−	−	0	gravel	−	−	+
Elodea canadensis	0	0	−	silt	−	+	−
Lemna minor	0	+	0	0	0	0	−
Nasturtium officinale	−	−	0	0	−	−	−
Phalaris arundinacea	0	0	0	0	0	−	0
Potamogeton crispus	0	0	+	silt	+	+	−
Potamogeton pectinatus	0	0	+	silt	+	+	−
Ranunculus longirostris	0	0	−	gravel	−	−	+
Veronica catenata	0	0	−	0	−	0	0

pectinatus is found in similar environments, except for preferences for sandy or silty environments.

Ranunculus longirostris was consistent with literature values. However, the distribution of *Veronica catenata* does vary significantly from literature reports. This discrepancy is due to the association of *Veronica* with *Ranunculus. Veronica* is often associated with clumps of other plants. This tendency has altered its usual distribution pattern (Haslam 1978).

Interstream Differences

Physical Environment

The light extinction of Black Earth Creek is significantly higher than that of Lawrence Creek (Table 2). This is due to higher turbidity from erosion, siltation and sewage effluent. Black Earth Creek also has greater canopy cover. These factors reduce potential macrophyte productivity (Krause 1977; Dawson and Kern-Hansen 1978; Dawson 1978, 1981). Whereas nutrients or substrate may limit growth in Lawrence Creek, light must be the limiting factor for growth in some stretches of Black Earth Creek.

Sediment

The sediments of the two streams differ significantly (Table 1). In the predominantly sandy sediment of Lawrence Creek, little organic matter and $CaCO_3$ are present. Black Earth Creek sediment has significantly higher percentages of gravel, silt, clay and organic matter. It is highly calcareous as well. These factors make the sediment of Black Earth Creek a better medium for rooting and for retaining nutrients.

Water Chemistry

Differences in geology, soil, and land use patterns result in important differences in water chemistry (Table 5). Significantly higher levels of ammonia and reactive phosphate occur in Black Earth Creek, probably from the application of fertilizers on adjacent agricultural fields and output from the sewage treatment plant. This is a recognized pollution problem (DCRPC 1980) and may account for the higher productivity of trout

Table 5. Summary of water chemistry data from Black Earth and Lawrence Creek with p-value from a Mann-Whitney two sample nonparametric test used to compare the two streams.

Test	*Black Earth Creek*	*Lawrence Creek*	*Mann-Whitney P-Value*[a]
pH	7.95	8.04	0.122
Ammonia (ppm)	0.29	0.03	0.013*
Nitrate (ppm)	1.56	1.85	0.225
Organic N (ppm)	0.33	0.57	0.153
Total N (ppm)	2.76	2.45	0.762
Reactive P (ppm)	0.26	0.07	0.100*
Total P (ppm)	0.31	0.08	0.110
Conductivity (mhos/cm)	465.5	304.7	0.011*
Alkalinity (mg $CaCO_3$/1)	281.6	158.9	0.006*
Turbidity (JTU)	4.60	1.57	—

[a] an asterisk (*) indicates significance at the p = 0.10 level.

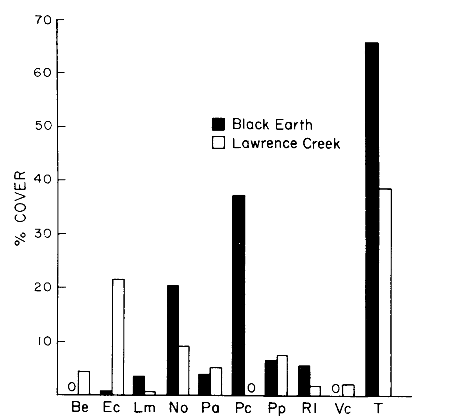

Fig. 14. Average percent cover of species and total macrophyte cover for Black Earth and Lawrence Creeks (Be, *Berula erecta;* Ec, *Elodea canadensis;* Lm, *Lemna minor;* No, *Nasturtium officinale;* Pa, *Phalaris arundinacea;* Pc, *Potamogeton crispus;* Pp, *Potamogeton pectinatus;* Rl, *Ranunculus longirostris;* Vc, *Veronica catenata;* T, total cover).

and aquatic macrophytes (Brynildson and Mason 1975). Higher alkalinity and conductivity in Black Earth Creek results from watershed soils and bedrock. Greater amounts of total dissolved inorganic carbon are available for photosynthesis, resulting in higher productivity in Black Earth Creek compared to Lawrence Creek (Adams *et al.* 1978a).

VEGETATION

One aim of this study is to compare quantitatively the differences in the vegetation of the two streams. This was achieved using Discriminant Analysis. The separation of the two streams by BMDP Discriminant Analysis was highly significant ($p < 0.001$) with a correct classification of 92.5% (86.9% for Black Earth Creek and 98.5% for Lawrence Creek; Figure 12). This analysis selected *P. crispus* and *R. longirostris* as representative of Black Earth Creek, with the higher cover values of *N. officinale* as somewhat representative of Black Earth Creek. *Berula erecta, E. canadensis* and *V. catenata* were chosen to represent Lawrence Creek, with *P. pectinatus* somewhat less important in discriminating the two streams on the basis of cover values. We then performed a BMDP Discriminant Analysis on the sections of each stream. This was also highly significant ($p < 0.001$), with a correct separation to each section of 93.0%. *Potamogeton crispus* and *R. longirostris* were selected again as representative of Black Earth Creek; *Berula erecta, E. canadensis* and *V. catenata* represented Lawrence Creek. *Nasturtium officinale* represented the upper sections of both streams, and *P. pectinatus* was indicative of the lower two sections of Lawrence Creek.

In general, growth is more luxuriant in Black Earth Creek. Total cover of macrophytes in Black Earth Creek averaged 75.2%, whereas in Lawrence Creek it was 49.5% (Figure 14). Ecological differences may also be seen from the species composition in each stream (Figure 14). The presence and success of *Potamogeton crispus* in Black Earth Creek indicates that the stream is mesotrophic or eutrophic, polluted and silted. The dominant species in Lawrence Creek is *Elodea canadensis,* which prefers quiet, clear waters and silt banks. This species is rare in Black Earth Creek, probably due to its intolerance of turbidity. The second most common plant in both streams is *Nasturtium officinale.* However, it covers twice the percentage of area in Black Earth Creek that it does in Lawrence Creek (Figure 14). This macrophyte is most common in the upper portions of both streams, due to cooler water temperatures. The third most common macrophyte in both streams is *Potamogeton pectinatus.* In each, it appears to fill a gap in stream habitat. In Lawrence Creek this is a spatial habitat of shifting sand in which other macrophytes cannot become established. In Black Earth Creek *P. pectinatus* occupies a temporal microhabitat left open after the mid-summer senescence of *P. crispus.* Other macrophytes are not as successful in the combination of pollution, turbidity and silt.

Ranunculus longirostris is also found in both streams, but achieves cover in Black Earth Creek five times that in Lawrence Creek (Figure 14). The limiting factor for *R. longirostris* in Lawrence Creek seems to be gravel substrate; it cannot root well in sand or silt. More than five times as many sites with appropriate gravel substrates occur in Black Earth Creek (Madsen 1982).

Both *Berula erecta* and *Veronica catenata* were found commonly only in Lawrence Creek; in the case of *B. erecta,* its absence in Black Earth Creek is due to its intolerance of siltation, pollution, and spates. *Berula* also prefers either fine sand or silt substrates. Less is known about *Veronica catenata.*

There is no significant difference in the occurrence of *Phalaris arundinacea* in the two streams. As it is generally a streambank species, this is an expected result.

Lemna minor is much more common in Black Earth Creek than Lawrence Creek, possibly due to a headwaters refuge and reproductive area, as well as many areas of slack water for habitation.

SYNTHESIS

In comparing the differences in vegetation between stream sections or two entire stream communities, confusion may occur. In studying sections or "reaches" of a given stream, slight differences in the environment or other factors may result in a slight difference in the community composition of those two sites. However, these differences are small when compared to the differences between the two streams, as in the case of Black Earth and Lawrence Creeks. Using Discriminant Analysis, this relationship can be seen (Figure 12). The differences between all sections except C and D are significant at the $p = 0.05$ level. The separation between the streams is significant at the $p = 0.01$ level. These relationships may be thought of in a hierarchical fashion, with the differences between sections or reaches being local and variable, and the differences between streams being of a larger scale and due to environmental differences characteristic of the streams.

ACKNOWLEDGMENTS

We thank Carolyn Madsen for her assistance in preparing and reviewing this manuscript, and the Davis Fund Committee (Department of Botany, University of Wisconsin-Madison) for providing travel funds for this project. An anonymous reviewer provided constructive comments.

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APPENDIX 1
Species observed in Black Earth Creek.

1. *Batrachospermum* sp. (Rhodophycophyta)
2. *Callitriche verna* (Callitrichaceae)
3. *Cladophora glomerata* (Chlorophycophyta)
4. *Draparnaldia* sp. (Chlorophycophyta)
5. *Elodea canadensis* (Hydrocharitaceae)
6. *Fissidens fontanus* (Muscopsida)
7. *Lemna minor* (Lemnaceae)
8. *Nasturtium officinale* (Brassicaceae)
9. *Phalaris arundinacea* (Poaceae)
10. *Polygonum* sp. (Polygonaceae)
11. *Potamogeton crispus* (Najadaceae)
12. *P. foliosus* (Najadaceae)
13. *P. pectinatus* (Najadaceae)
14. *Ranunculus longirostris* (Ranunculaceae)
15. *Sagittaria brevirostra* (Alismaceae)
16. *Solanum dulcamara* (Solanaceae)
17. Typha angustifolia var. *elongata (glauca?)* (Typhaceae)
18. *Veronica catenata* (Scrophulariaceae)

APPENDIX 2
Species observed in Lawrence Creek.

1. *Alnus rugosa* (Betulaceae)
2. *Amblystegium riparium* (Muscopsida)
3. *Berula erecta* (Apiaceae)
4. *Caltha palustris* (Ranunculaceae)
5. *Cladophora glomerata* (Chlorophycophyta)
6. *Drepanocladus* sp. (Muscopsida)
7. *Elodea canadensis* (Hydrocharitaceae)
8. *Lemna minor* (Lemnaceae)
9. *Machantia* sp. (Hepaticopsida)
10. *Mentha arvensis* (Labiaceae)
11. *Nasturtium officinale* (Brassicaceae)
12. *Phalaris arundinacea* (Poaceae)
13. *Polygonum* sp. (Polygonaceae)
14. *Potamogeton pectinatus* (Najadaceae)
15. *P. richardsonii* (Najadaceae)
16. *Ranunculus longirostris* (Ranunculaceae)
17. *Solanum dulcamara* (Solanaceae)
18. *Symplocarpus foetidus* (Araceae)
19. *Veronica catenata* (Scrophulariaceae)

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