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ELIZABETH McCOY

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EDITORIAL POLICY

The *Transactions* of the Wisconsin Academy of Sciences, Arts and Letters is an annual publication devoted to original, scholarly papers, some preference being given to the works of Academy members. Sound manuscripts dealing with features of the State of Wisconsin and its people are especially desirable, although other papers of merit are also acceptable. Subject matter experts will review each manuscript submitted.

Contributors are asked to submit *two copies* of their manuscripts to the Editor. The manuscripts should be typed on 8½ x 11" bond paper. The title should be at the top of the page, *typed in capital letters throughout.* The author's name and brief address should appear below the title and toward the right hand margin. It should be typed with capital-lower case style and the address portion underlined for italics. Each page of the manuscript beyond the first should bear a page number and author's name for identification; e.g. 2–Brown, 3–Brown, etc. A note on separate sheet, submitted with the manuscript, should identify the author with his institution, if appropriate, or with a personal address for the Editor's use in correspondence.

The style of the text should be that of scholarly writing in the field of the author but to minimize printing costs the Editor requests that the general form of the current volume of *Transactions* be examined and followed so far as possible. For the Science papers an ABSTRACT is requested. Documentary Footnotes may be useful, especially for the Arts and Letters manuscripts, and, if needed, should be typed as a group on separate sheets and numbered for citation in the text. Such FOOTNOTES will be published at the end of the text in place of BIBLIOGRAPHY. For BIBLIOGRAPHY of Science papers or of any papers at the author's choice, references should be assembled alphabetically and typed on sheet or sheets as needed; citations in the text are usually by author and date in parentheses. The style of references will be standardized as in the current volume, to promote accuracy and reduce printing costs.

The cost of printing the *Transactions* is great. Therefore excessively long papers will not ordinarily be accepted. In the rare instance of such a long paper or of some especially costly printing or illustrations, the author may be asked to subsidize publication.

Galley proofs and manuscript copy will be forwarded to the senior author for proof reading prior to publication; *both* should be returned to the Editor within *ten days.*

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Papers received on or before November 15 will be considered for publication in the 1975 volume of *Transactions.* Manuscripts should be sent to the Editor at the W.A.S.A.L. office above.

LOUIS W. BUSSE

51st President

WISCONSIN ACADEMY OF SCIENCES, ARTS
AND LETTERS

TOWARD A NEW MATURITY: THE WISCONSIN ACADEMY IN ITS SECOND CENTURY

Presidential Address
Louis W. Busse
President 1972–73
Ripon, Wisconsin
April 27, 1973

President-elect Perrin, Members of the Council, Colleagues of the Academy, and Friends:

On the First of February, 1870, J. W. Hoyt and 104 of Wisconsin's finest scholars, governmental leaders, and noted citizens circulated about the state a "Call for a Meeting to Organize." The Wisconsin Academy of Sciences, Arts and Letters was about to be born. It was to be, in the words of the authors of the Call, ". . . an institution that shall be of great practical utility and lasting honor to the State."

For a number of years the idea for such an institution had been in the hearts and minds of many. As the language of the Call indicates, the founders of the Academy were motivated by the premise that ". . . the prosperity and power of a State depend not more upon its material resources than upon the culture of its people and the extent of their knowledge of nature and man." They incorporated this belief within the charter through the listing of such purposes as:

1. Researches and investigations in the various departments of the material, metaphysical, ethical, ethnological and social sciences;
2. A progressive and thorough scientific survey of the State, with a view to determining is mineral, agricultural and other resources;
3. The advancement of the useful arts, through the applications of science, and by the encouragement of original invention;
4. The encouragement of the fine arts by means of honors and prizes awarded to artists for original works of superior merit;
5. The formation of scientific, economical and art museums;
6. The encouragement of philological and historical research, the collection and preservation of historic records, and the formation of a general library; and
7. The diffusion of knowledge by the publication of original contributions to science, literature and the arts.

It was, as can be seen, an undertaking cast in a philosophy and purpose of substantial magnitude. That the Academy was to succeed in the fulfillment of much of what it had been charged to accomplish, given its financial limitations, is a high tribute to its leadership and to its membership. Through the course of nearly all its first century of existence, the Wisconsin Academy achieved *despite,* not because of, its monetary resources. The question must always remain: What proud paths might we have traveled and realized what goals had there been a more adequate fiscal base?

I submit to you, however, that a comparable question must be answered today. While the coffers of the Academy are far from overflowing, the fact remains that, thanks to the generosity of such as our late colleague, Dr. Harry Steenbock, our friend and fellow member, Dr. Elizabeth McCoy, and others, we are now in a position to realize goals dreamed of by our illustrious founders and to travel some of the paths chartered by these people. We can no longer plead lack of monetary resources for future failures.

In looking toward a new maturity, there are several ways to look at the Academy. One of them might be to consider the Academy as a 100 years old adolescent, who never quite reached maturity because of a shortage of one *essential hormone*—that of fiscal resources (money). Suddenly in 1969 he received a $950,000 injection—and now, as a rapidly growing youth, is trying vigorously to find himself and to mature.

Or, we can look at ourselves as a 100 year-old institution or organization, seeking renewal with the vitality of a youngster stimulated by the faith of several individuals in our goals and objectives and their generosity to help us achieve or make progress toward these goals. When we mention the vitality of a society or institution or organization we must include the vitality of its individual members. The society and its members are one and the same. A society or an organization decays when its institutions and individuals lose their vitality. As I have viewed the Academy over these past three years, I see members of long standing and new members demonstrating a new vitality and interest which speaks well for our future.

You know, one of the fascinating things I have found in the Academy is its resilience—its constant ability to renew itself. When organizations and societies are young, they are flexible and fluid, not yet paralyzed by rigid specialization. As they age, however, vitality diminishes, flexibility gives way to rigidity, creativity fades in this environment and finally there results a loss of capacity to meet challenges from unexpected directions. I view the Academy as now at the beginning of a new *maturing period.* This is necessary for we cannot and should not remain forever with the confusion of youth. The question to which the Academy will have to seek the answer is: How can it become a mature organization and still retain the flexibility and adaptability characteristic of youth which permit the ever renewing process, when, in fact, the processes of maturing are essentially those that reduce flexibility and adaptiveness.

I do not have the answer, of course, but I would assume that the first step would be to recognize the facts: to *know the difference*, that is, the difference between *maturity* and *rigidity or lack of flexibility*. So, I would urge our future leaders and especially our members to constantly be on the alert for the appearance of those disastrous side effects of the maturing process and to treat these quickly as they appear. In this kind of an organization, the ever-renewing process can take place, and then what matures is an organization or framework within which continuous innovation, renewal and rebirth can occur. I think this is what we all want for the Academy and with your help we can develop this kind of organization.

Now, before an organization can proceed toward its major objectives and program goals, it must have a certain *stability*. It must have its machinery in working order. It must solve its day-to-day operating problems and get out from under these uncertainties. It must get out of the confusion of youth.

I thought tonight I might make a portion of my message to you in the form of a "report from your President." This is not to set a precedent for future presidents. However, your Academy has had three busy years—two under the leadership of Norman Olson and F. Chandler Young, and this past year with me and Dick Perrin. These were good years for me and I greatly appreciated the opportunity to serve with all of these people.

I would like to indicate some of the significant events or happenings over this past year for I think they reflect stages in the maturing process that the Academy is now going through, and they give proof to the claim that we are getting our house in order and going on to greater accomplishments.

THE FIRST EVENT

Of great significance to the Academy was our success in clarifying our tax status with the Internal Revenue Service. As some of you know, due to errors in previous reporting to the Revenue Service we were classified as a private foundation and our income from our investments, thus, would be taxable. This classification was an intolerable situation for the Academy. Therefore, competent legal counsel was retained and the Academy's income, operating expenses, and contributions were properly identified and established. A brief was prepared and submitted to the I.R.S. and just last month we were notified of our new classification as a tax-exempt foundation. This had to be established in order for the Academy to continue to develop to its full potential. It pleases me to be able to report our success in this effort. The amount of staff time which went into this effort was enormous and how our Director was able to keep anything else going is testimony to his effort. In this relation also I must acknowledge the help of Walter Scott and express my appreciation for the tremendous help he was in leading us and supplying us with information on the Academy.

In order to protect the Academy from any further mistakes in this area and because of the increasing activities of the Academy which may have legal implications needing interpretations, I have recommended to the Council (and they have approved) the contracting of legal services on a retainer basis. We have secured the services of the law firm of Werner, Lathrop, Heany, which handled our tax case.

One of the other events which gave me real pleasure was to observe and work with Bob Dicke and our Facilities Committee. Bob was persistent and insistent that a basement office in a lumber yard was no place for a distinguished organization such as ours. Bob believed in the "shock technique." He first came to the Council, as many of you know from our meeting last fall, and presented a plan which involved an expenditure of some $350,000. First, he got all of us to agree that our location at that time just was not acceptable and then in turn he agreed that maybe $350,000 was a little high and that he and his Committee would look again. So, when he came back with a request to the Academy to purchase a $70,000 building, which was on University Avenue and just off campus, we were relieved to get off that easily.

I am especially enthused with our new headquarters building at 1922 University Avenue, which the Academy has purchased and is remodeling for its needs. It was purchased with capital gains from our investment trust for $67,500. Our distinguished member, Dr. Elizabeth McCoy, suffered through this agonizing period with us, and very early in our deliberations offered us a location on her farm or estate along with a contribution of $22,500 to remodel a building there. This we considered very seriously but hesitated only because of the distance from the campus and central city. However, when she saw Bob's and my pleasure at the opportunity of the University Avenue site she couldn't resist and said, "This is what you need; it's the right location; and it is fitting for the Academy." After another two seconds she said, "What's more, I'll round it off to $25,000 toward the purchase or remodeling, whichever you wish." Ladies and Gentlemen, that's why you have a home, a headquarters building, an image if you will, and one in which you may feel happy and comfortable for many years.

It's a charming little building, a delightful place for the staff to work in, and an extremely pleasant place to visit. I know you will be pleased and I urge you to come and see it and experience the revitalization, the renewed effort that this facility has stimulated in all of us. We will be moving in on Tuesday, May 1 and although it will not be completely furnished, we might be able to find you a chair to sit down on.

The acquisition of the building and the contracting for remodeling and redecorating services has taken a tremendous number of hours of staff time this past month, so if some of the daily routine or deadline schedules were not met, please bear with us for another month or so.

Another event, with rather severe implications for the Academy, was the establishment by the Governor of a task force on the status of the arts and humanities in Wisconsin with Dean Adolph Suppan, a past president of the Academy, as its Chairman. The task force did hold several meetings in the state and in Madison, but for some reason neither I nor our staff were made aware of the work of this committee until just a few months ago. The recommendations of the Committee were already formulated and the Governor already had in his budget the funds for the establishment of a State Board for the Arts and Humanities. This board is to disperse the funds contributed to the arts in Wisconsin by the National Endowment for the Arts and thus will relieve the Arts Council of the state of this responsibility.

As many of you know, this situation resulted in the resignation of Mr. Lauch as Executive Director of the Arts Council and the publishing in the Milwaukee Journal of an interview with him in which he denounced the work of the task force and took serious exception to the creation of this new board or state agency.

Even though it was late to intervene, I felt that the implications for the Academy were so great that appearance was necessary in opposition to the bill at the hearing before the Joint Finance Committee. Mr. Batt and I appeared there and spoke in opposition and presented the Committee with much material relating to the Academy's activities in the Arts and Humanities. Needless to say, the Committee was very surprised there was such an organization closely connected to the State by charter, already performing these functions, and seemed pleased to be made aware of this alternative. I can inform you that the staff of this committee considered three alternatives for the responsibility:

1. To leave in the hands of the Arts Council;
2. To place in the hands of the Academy of Sciences-Arts-Letters;
3. To follow the Governor's recommendation for a new State Board.

Mr. Davis, of the Committee, informed us that the Committee is recommending going along with the Governor's proposal.

In spite of this, the Academy will continue to maintain a vigorous program for the Arts and Letters, and will work with the Board, if and when one is created.

Two other areas in which progress has been made in the past two years has been in membership and publications—the vitality and life blood of our organization.

We have increased our membership by approximately 300 and quadrupled our life memberships. The new membership directory has been published and it makes an impressive appearance. Membership drives will continue and in the meantime all of us as individuals can help tremendously by each bringing in a new member next year. Doubling our membership next year would be an encouraging step.

I am particularly pleased with the improvement of our publications this past year and I hope that you are too. The TRANSACTIONS has always been an exemplary publication. Now, the ACADEMY REVIEW has been expanded and takes on a new look, and I think does the Academy proud. The last two issues were particularly good and carried a good balance between our three cultures.

In addition, you now have received an issue or two of the ACADEMY TRIFORIUM, our new monthly newsletter, designed to keep you informed of Academy developments in a more up-to-date manner. I think it is interesting and will help to keep the Academy in the forefront of our minds and our interest.

Publications, to my mind, are the life blood of the Academy and will determine its future. I think it is essential that the Academy have an extensive publishing program for it is only through this mechanism that we can really create and maintain the image and the status we seek. Our publications will determine whether the mass of the membership continues to remain in the Academy or to withdraw for lack of contact with our programs and objectives.

This is costing the Academy money; however, early results seem to indicate it will also bring in money. Nevertheless, the budget for 1973–74 will show a significant increase in the item for publications. In addition, this cannot be accomplished without increased manpower and so our budget will show that we have acquired the full time services of Miss Monica Janigh. One could say that we are doing it with womanpower instead of manpower.

Seriously, I think our staff, Jim, Nancy, Marie and Monica, are doing an excellent job in their areas of Academy responsibility and we owe them a vote of thanks for their dedication.

These accomplishments, I like to think, are in the category of getting our house in order:

1. Our status as a tax-exempt organization
2. A house befitting our image with adequate space and facilities to do our job
3. Publications reflecting our progress toward our goals and objectives.
4. Membership buildup

Significant progress has been made in all of these this year.

We are now just in the process of assessing our future role and goals, hopefully exhibiting the vitality, flexibility, and adaptability necessary to assure our success. There are two things I would like to mention in this regard.

First is the reorganization of our Junior Academy, which has been growing rapidly under the direction of Mr. LeRoy, Lee. More high schools are participating, more students are participating, more institutes for both school and summer months, are being organized. I think over 600 students have been at the various institutes this past year.

In our reorganization, we will be dropping the Junior Academy nomenclature and thus not have a separate organization. Instead, we will have a youth program in which these students are associate members of the Academy which will make them feel more a part of us—an example of our adaptability and flexibility. I look for this aspect of our activity to mushroom over the next years and I am sure that it will require a full-time director for this program in a few years. As an example, the Academy, through the efforts of LeRoy and Jim, is the recipient of a grant of $7,500 from the Atomic Energy Commission to sponsor institutes on our energy crisis at the high school level. There is no end to the kinds of programming the Academy can sponsor and develop for these young people. However, as we involve ourselves more with the young crowd, or to put it the other way, as we take the young people more into our establishment, we must be prepared to accept change and to have the framework which will accept and permit constructive changes.

Second, I would like to mention some of our efforts to decide our future roles and objectives. In this respect I would like to express my appreciation to Bob Gard and Don Emerson for their contributions. In the role of *stimulators,* particularly in the Arts and Letters, the Academy is embarking on the following pathways:

1. The Council has authorized an Academy literary award of $5,000 for the best book published by a Wisconsin author or author with Wisconsin heritage, to be given in 1976 as a part of the Bicentennial celebration.
2. We are giving citations in "The Theatre" category and Professor Gard informs us he has already had the pleasure of presenting one award on

behalf of the Academy before an audience of 600–700 people in Stevens Point, who were thrilled at the recognition bestowed upon them by our organization.

3. We are also establishing a Citation for the best book in Science published by a Wisconsin author and it will be presented by and for the Wisconsin Library Association.

4. Our Fall Gathering probably will be held in Ft. Atkinson this September 22 and 23 in conjunction with the Wisconsin Regional Writers Association and the dedication of the Wisconsin Authors Hall of Fame.

I mention all of these items to you because they indicate to me two things: (1) the Academy is actively seeking to find its role in its relationship to the specialty organizations making up the Arts and Letters; and (2) is attempting to bring them into our Academy home and to nourish them as individuals in any way we can. I think this is marvelous progress, and much credit should go to our Vice Presidents and to our Executive Director.

In this same vein, Dick Perrin will be appointing a committee to study the feasibility and mechanism by which the Academy could enter into a cooperative arrangement with the U. W. Extension Division in support of a faculty member who would work at the Academy offices. This person would study the role of the Academy as a co-ordinator for all of the Arts and Letters organizations in the state and develop a procedure by which the activities of these organizations could come under the umbrella of the Academy. In addition, he will determine how the Academy can help these organizations to fulfill their goals and objectives. If this were to come about and prove to be successful, I can visualize a similar role in the Sciences and with this kind of work power the Academy should be able to fulfill the goals and objectives so forcefully stated in our Charter of 1870. I do look for this to happen!

In closing, let me say these have been three wonderful years. I hope I may continue to serve the Academy in the future. As you know, Wisconsin is one of the few Academies of Science which encompasses the Arts and Letters as well. As a pharmacist and scientist one of the real pleasures of this opportunity to serve you was the chance it gave me to meet and know so many people in the other cultures, and to know and understand the working of the mind of the artist and the writer. I hope similarly it gave the artist and the writer a closer view of the thinking and the orientation of the minds of the scientists and professionals. I no longer think of the artist and writer in an adversary relationship and I hope they too can begin to see professionals and scientists in non-adversary relationships.

I think it is extremely important to stable progress in our Academy that these adversary relationships between these cultures be reduced and that this be replaced by mutual understanding. It seems to me that this is a particularly significant role for the Academy to perform, and since it is an organization of all three cultures it is ideally suited to perform it. Members of the Academy, if the Academy can accomplish this for me, I know it can accomplish it on a much greater scale for the people of our state. I urge you to make this a major effort in the next years.

It has been an honor and a pleasure to serve you.

And now it is my privilege and pleasure to turn the reins of the Academy over to your President-elect, Richard Perrin, who now becomes your President for the coming year. I hope I give the Academy to you in as good a state as it was when it was turned over to me by President Young. I know the Academy will be in good hands. Members, your new President, Mr. Richard Perrin.

A HEMLOCK RELICT ALONG LAKE MICHIGAN, SHEBOYGAN COUNTY, WISCONSIN

Thomas Foster Grittinger
University of Wisconsin—Center Sheboygan County—Campus—Sheboygan

Hemlock (*Tsuga canadensis* (L). Carr.)* had been reported along Lake Michigan as far south as Sheboygan County by surveyors (Goder, 1955). The southernmost stands mapped along the lake are listed as relicts in Manitowoc County; however a few scattered hemlocks can still be found within 50 feet of the shoreline in Sheboygan County (Goder, 1955). This report is an analysis of a well established stand composed mostly of hemlock, found east of Oostburg in Sheboygan County (Fig. 1). Despite the southern location of this northern community and its disjunct nature, it is rich in species and the hemlock is vigorous.

This hemlock stand lies on old dunes between the more recent dunes to the east and the swampy swales covered with lowland hardwood to the west. Farther west a steep bluff of Nippissing age separates the agricultural uplands from the forested lowlands along Lake Michigan. The bluff appears to provide a wind shadow from the prevailing dry westerly winds. East of the hemlock the younger dunes support white pine (*Pinus strobus* L.), white cedar (*Thuja occidentalis* L.), white birch (*Betula papyrifera* Marsh.), and green ash (*Fraxinus pennsylvanica* Marsh. var. *subintegerrima* (Vahl) Fern.). This forest buffers the hemlock community from the easterly and northeasterly winds off Lake Michigan. The hemlock stand thus receives protection from both the prevailing summer winds and the winter storms.

The proximity to Lake Michigan has a major impact on the climate. Lake effects such as a cooling in the spring and early summer when onshore breezes are common, a high frequency of local fogs, postponement of the first killing frost in the fall, delay of bud opening in the spring, as well as persistence of snow cover near the shore in the winter when the lake acts as a cloud generator and a heat and moisture source are well known (U.S. Dept. Comm., 1961; Bruncken, 1910; Whitford and Salamun, 1954; and Lyons, 1970). These climatic effects account for the southward extension of northern forests along the lake. Northern species have

* The nomenclature used here is according to Fernald (1950).

FIGURE 1

been recorded as far south as Grant Park in Milwaukee County (Bruncken, 1910; and Whitford and Salamun, 1954).

SAMPLING METHODS

The quarter method was used to examine tree composition and structure in the stand. The trees reported include stems over 4 inches in diameter at breast height (d.b.h.). Quadrats 4 x 4 meter square were used for shrubs and saplings, and 1 x 1 meter quadrats were used for herbs and seedlings. Saplings included stems with diameters of 1 to 4 inches, seedlings with diameters below 1 inch, and shrubs, multistemmed woody species that generally do not reach tree size. Quarter points and the quadrats were placed at 50 foot intervals along compass lines. To cover most of the stand, three compass lines were used with a total sample of 50 quarter points and quadrats of each size. Relative frequency, relative density, and relative dominance were calculated for tree species and these values were summed to give an importance value (Cottam and Curtis, 1956). Quadrat data provided relative frequency and frequency.

RESULTS AND DISCUSSION

The community includes many species typical of the northern coniferous forests and even the boreal forest (Curtis, 1959); see

Tables 1, 2, and 3. For example, hemlock, beech (*Fagus grandifolia* Ehrh.), red-berried elder (*Sambucus pubens* Michx.), Solomon's Seal (*Polygonatum pubescens* (Willd.) Pursh), and club-moss (*Lycopodium lucidulum* Michx.), all species that achieve their highest presence values in the northern mesic forest, are common throughout this community. White pine, red maple (*Acer rubrum* L.), white birch, and wild sarsaparilla (*Aralia nudicaulis* L.), characteristic of the northern dry-mesic forests, are present; white pine is especially common on the dune ridges. The northern wet-mesic forests contain yellow birch (*Betula lutea* Michx.), black ash (*Fraximus nigra* Marsh.), and white cedar. Yellow birch is found throughout the stand; black ash and white cedar are frequent in the low, moist depressions between dune ridges. Species of the boreal forest, mountain maple (*Acer spicatum* Lam.), large-leaved aster (*Aster macrophyllus* L.), bluebead-lily (*Clintonia borealis* (Ait.) Raf.), wild lily-of-the-valley (*Maianthemum canadense* Desf.), star-flower (*Trientalis borealis* Raf.), fly-honeysuckle (*Lonicera canadense* Bartr.), and twisted-stalk (*Streptopus roseus* Michx.) are also present in this stand. *Viola Selkirkii* Pursh., which occurs in this community, is noted by Fassett (1959) as present along the northern borders of Wisconsin, "south to Clark and Door Counties, and in cold canyons at Devil's Lake and the Dells of the Wisconsin River". Many other species found here with low frequencies also exhibit their highest presence values in northern Wisconsin. Northern species seen but not encountered in the quadrats include goldthread (*Coptis groenlandica* (Oeder) Fern.) and bunchberry (*Cornus canadensis* L.).

Northern plant communities are reasonably frequent near Lake

TABLE 1. PHYTOSOCIOLOGICAL DATA ON TREE SPECIES[1]

Species	Relative Frequency	Relative Density	Relative Dominance	Importance[2] Value
Tsuga canadensis (L.) Carr.	33.3	47.5	57.4	138.2
Acer rubrum L.	14.3	12.5	9.2	36.0
Betula lutea Michx.	13.5	11.5	8.3	33.3
Betula papyrifera Marsh.	9.5	7.0	5.6	22.1
Acer saccharum Marsh.	7.1	5.5	4.3	16.9
Fagus grandifolia Ehrh.	4.8	3.0	3.2	11.0
Pinus Strobus L.	3.2	2.5	4.3	10.0
Quercus rubra L.	3.2	2.0	2.0	7.2
Tilia americana L.	2.4	2.5	2.2	7.1
Fraxinus pennsylvanica Marsh. var. *subintererrigma* (Vahl) Fern.	3.2	2.0	1.6	6.8
Thuja occidentalis L.	2.4	2.0	1.6	6.0
Fraxinus nigra Marsh.	2.4	1.5	0.2	4.1
Pyrus americana (Marsh.) DC.	0.8	0.5	0.2	1.5

Average distance between individuals = 13.6 feet Trees/acre = 235.6

[1]Quarter method, 50 points used
[2]Importance value = relative frequency + relative density + relative dominance

TABLE 2. FREQUENCY VALUES FOR SHRUBS AND SAPLINGS

Species	Frequency	Relative frequency
Acer spicatum Lam.	66.0	41.8
Prunus virginiana L.	26.0	16.4
Sambucus pubens Michx.	26.0	16.4
Tsuga canadensis (L.) Carr.	8.0	5.1
Lonicera canadensis Bartr.	8.0	5.1
Tilia americana L.	4.0	2.5
Rubus pubescens Raf.	4.0	2.5
Ribes lacustre (Pers.) Poir.	4.0	2.5
Ilex verticillata (L.) Gray	2.0	1.3
Hamamelis virginiana L.	2.0	1.3
Corylus cornuta Marsh.	2.0	1.3
Acer rubrum L.	2.0	1.3
Ribes spp.	2.0	1.3
Symphoricarpos albus (L.) Blake	2.0	1.3

TABLE 3. FREQUENCY VALUES FOR SEEDLINGS AND HERBS

Species	Frequency	Relative frequency
Polygonatum pubescens (Willd.) Pursh	58.0	11.3
Trientalis borealis Raf.	50.0	9.8
Clintonia borealis (Ait.) Raf.	44.0	8.6
Maianthemum canadense Desf.	44.0	8.6
Acer spicatum Lam.	34.0	6.6
Acer saccharum Marsh.	28.0	5.5
Aster macrophyllus L.	28.0	5.5
Claytonia virginica L.	26.0	5.1
Dryopteris spinulosa (O. F. Muell.) Watt	26.0	5.1
Aralia nudicaulis L.	24.0	4.7
Viola pensylvanica Michx.	20.0	3.9
Viola Selkirkii Pursh	16.0	3.1
Various grasses *and sedges*	16.0	3.1
Arisaema triphyllum (L.) Schott	12.0	2.3
Lycopodium lucidulum Michx.	12.0	2.3
Streptopus roseus Michx.	8.0	1.5
Caulophyllum thalictroides (L.) Michx.	6.0	1.1
Allium tricoccum Ait.	4.0	.8
Anemone quinquefolia L.	4.0	.8
Cardamine Douglassii (Torr.) Britt.	4.0	.8
Circaea alpina L.	4.0	.8
Galium triflorum Michx.	4.0	.8
Impatiens capensis Meerb.	4.0	.8
Mitchella repens L.	4.0	.8
Prunus virginiana L.	4.0	.8
Solanum dulcamara L.	4.0	.8
Trillium cernuum L.	4.0	.8
Actaea rubra (Ait.) Willd.	2.0	.4
Athyrium Filix-femina (L.) Roth	2.0	.4
Corylus cornuta Marsh.	2.0	.4
Dryopteris disjuncta (Ledeb.) C. V. Mort.	2.0	.4
Erythronium americanum Ker.	2.0	.4
Onoclea sensibilis L.	2.0	.4
Osmorhiza Claytoni (Michx.) C. B. Clarke	2.0	.4
Pyrus americana (Marsh.) DC.	2.0	.4
Rubus pubescens Raf.	2.0	.4
Sanguinaria canadensis L.	2.0	.4

Michigan in Sheboygan County. This forested strip consists largely of white pine and hardwoods on mesic sites or black ash and white cedar on lower areas. Hemlock is infrequent and appears to be a disjunct species.

In this community hemlock represents by far the most important tree species, with an importance value of 138.2 (Table 1). Other trees found include in descending order of importance: red maple, yellow birch, white birch, sugar maple (*Acer saccharum* Marsh.), beech, white pine, red oak (*Quercus rubra* L.), basswood (*Tilia americana* L.), green ash, white cedar, black ash, and mountain ash (*Pyrus americana* (Marsh.) DC.). This is in contrast to the stands examined by Stearns (1951) where sugar maple, with a relative frequency of 89%, a relative density of 41.8%, and a relative dominance of 28%, had the greatest importance value; hemlock followed the sugar maple with a relative frequency of 67.6%, a relative density of 22.3%, and a relative dominance of 23.8%. Numerous large trees gave hemlock high relative dominance. Old hemlock stumps in the stand suggest the possible ages of these large trees. Three stumps ranged in age from 118 years for a 24 inch diameter stump to 184 years for a 29 inch stump. However estimation of hemlock from stem diameters is subject to error, largely because hemlock tolerates suppression (Curtis, 1959). Stearns (1951) found that hemlock may experience several periods of suppression before finally reaching a position of dominance in the canopy. In this community, hemlock attains a greater size than other species save for white pine. The white pine also has a high relative dominance but is not present as seedlings or saplings, although it is present in various sizes as trees. Although no hemlock seedlings were encountered in the quadrats (Table 3), they were often seen on old stumps (Fig. 2).

Hemlock shows a high relative density, compared to relative frequency. Favorable sites for seed germination are rotting stumps and logs, and tip-up mounds; all of these microhabitats are common in this community. The stumps resulted from the infrequent removal of a few trees. Relatively shallow root systems and loose sandy soil account for the high percentage of windthrown hemlock. The importance of windthrow in creating sites for germination and in opening the canopy for hemlock has been documented (Goder, 1955). Reproduction on stumps is seen in this community (Fig. 3). Thus hemlock creates its own environment for reproduction (Goder, 1961). Since the microhabitats so created tend to occur in specific limited situations, clumping of trees inevitably results. The presence of dense island-like groupings of hemlock was noted by Stearns (1951).

Hemlock is considered preferred deer food (Swift, 1946); however, the deer population is low in this area perhaps because many of the lakeshore cottages and nearby homes are occupied throughout the year. Hemlock, if browsed, has little chance for recovery (Curtis, 1959). Elsewhere along Lake Michigan, deer populations

FIGURE 2

have grown rapidly and browse lines are visible in places within Milwaukee County (Forest Stearns, personal communication).

In addition to hemlock, other trees appear capable of continuing in the community under present conditions. Both red maple, and especially sugar maple, in all size classes are present throughout. Yellow birch was found in many sizes, with many exhibiting the prop rooted condition mentioned by Curtis (1959); this condition is the result of seedling development on rotting logs and stumps with the subsequent decomposition of the log or stump. In spite of this unique method of early development, yellow birch reproduction is very successful on moist, mineral soil surfaces (Curtis, 1959), and heavy windfall or partial cutting will permit an increase in yellow birch reproduction (Stearns, 1951). White birch apparently owes its presence to localized disturbances, since it is a gap-phase tree found in small openings in the forest (Curtis, 1959). Beech can be expected to continue reproducing in this community; this species maintains itself by vegetative reproduction (Ward, 1956).

The origin of this community is tied to long term lake level changes, to the development of sand dunes and their stabilization, and to continuing disturbances. After the moving dunes are colonized and stabilized by vegetation, an orderly process of plant succession takes place, which eventually terminates in a mesic

FIGURE 3

forest (Cowles, 1899; Olson, 1958a and b; and Curtis, 1959). However since 800 to 1000 years are required to progress from initial stand to a climax mesic forest, such uninterrupted successions are very rare (Curtis, 1959). Disturbance is indicated by white pine, white birch, and red oak. The presence of white pine as scattered individuals of uneven age in a mixture of hemlock and climax hardwoods is due to relatively small openings caused by windfall or some other purely local influence (Nichols, 1935). The presence of continuing disturbance in this community is further demonstrated by hemlock and yellow birch which require wind-produced clearings in order to compete with sugar maple in a mixed stand of sugar maple, hemlock, and yellow birch (Stearns, 1949). Stearns (1951) further suggests that where hemlock exists in clans or dense groups, it is probably due to mass establishment following some occurrence which not only opened up the forest canopy but which also coincided with favorable seed years and favorable climatic conditions. The preference of pure stands of hemlock for very moist situations may be related to the increased frequency of heavy windfall in shallow rooted trees and with the moisture requirements for seed germination (Stearns, 1951).

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THE *ROTH* CASE: THE BURGER COURT AND JUDICIAL RESTRAINT

Warren R. Wade
University Wisconsin—
Stout Menomonie

When the United States Supreme Court announced its decision in *Roth v. The Board of Regents of the State Colleges*[1] on June 29, 1972, it made a ruling of landmark significance in the law governing academic personnel matters. The Court held that non-tenured faculty members have no constitutional right to a statement of reasons or to a hearing in cases regarding non-retention.

The *Roth* case was surrounded by a great deal of notoriety and publicity which caused many individuals and groups, in addition to the plaintiff, Dr. David Roth, an Assistant Professor at Oshkosh State University, to become interested in its outcome. Several other non-tenured faculty members whose contracts had not been renewed by the Wisconsin State University System were anxiously awaiting the Court ruling. At the same time, college presidents, vice-presidents, deans, and department chairmen throughout Wisconsin quivered at the mere mention of the possibility that the lower federal courts' decisions (which maintained that non-tenured faculty were constitutionally entitled to a statement of reasons and a hearing in a non-retention case) would be sustained. Although most college administrators in the rest of the country probably had not heard of the *Roth* case, several state and national associations, representing their interests, had filed *amici curiae* briefs on behalf of the defendant-appellant Wisconsin State University Board of Regents, arguing that detrimental results would occur if the lower court decisions were not reversed.[2]

The *Roth* case is unique because it marked the first time that the Court had addressed itself to the issue of what procedural rights the Constitution guarantees a non-tenured teacher. This paper approaches *Roth* as a case study attempting to identify the kinds of factors and events capable of generating a legal controversy of sufficient magnitude to cause the nation's highest judicial

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1 408 U.S. 654 (1972).

2 Briefs were filed by the following: the Board of Governors of State Colleges and Universities of Illinois; the Board of Regents of Regency Universities of Illinois, the Board of Trustees of Southern Illinois University; the American Association of State Colleges and Universities; and the American Council on Education and the Association of American Colleges; by Attorneys Albert E. Jenner, Chester T. Kamin, and Richard T. Franch, 135 South La Salle Street, Illinois 60603.

tribunal to deem it worthy of a hearing. The development of the controversy is traced from its origin in late November, 1968 to its final adjudication on June 29, 1972 and includes a description of the original plaintiff, Roth, the charges made against him, and an analysis of the three federal court opinions in the case.

EVENTS LEADING TO THE NON-RETENTION DECISION

The events leading to the non-retention of Dr. David Roth in the Political Science Department at Oshkosh State University, Oshkosh, Wisconsin (now known as the University of Wisconsin—Oshkosh), were extremely complicated, as evidenced by the conflicting interpretations of Roth's actions as well as the events surrounding the case. Although several of the charges against Roth can be accurately documented, many diverse opinions were offered as to their verity or falsity. Out of the numerous interviews with many of the parties involved, including Roth himself, and through extensive examination of reports, legal briefs, newspaper articles, and federal court opinions, this writer has attempted to make a fair judgment as to why Roth's contract was not renewed for the 1969–1970 academic year in addition to the important legal and constitutional implications for state control of educational disciplinary matters.

The events leading to Roth's non-retention initially arose out of the suspension of ninety-four Oshkosh black students after a confrontation involving the occupation of President Roger Guiles' office on November 21, 1968. The black students were protesting against President Guiles' alleged insensitivity to their demands for more black instructors, additional black studies courses, a black culture center, and better counseling services for black students. President Guiles, arguing that it was administratively and financially impossible for him to do so, refused to agree to the demands whereupon one student yelled, "Do your thing." With this, bedlam broke loose. His desk and files were overturned and their contents scattered around the room. Typewriters were thrown on the floor, tables were overturned, draperies were torn, and a calculator was thrown out the window, causing damage in excess of $7,000. All ninety-four students were arrested and immediately suspended from classes.

Although Roth had not been involved with black students on the Oshkosh campus prior to the disturbance in the president's office, in the two or three weeks following it he became the center of attention. One Oshkosh faculty member maintained that Roth acted more like a student leader than a faculty member during these weeks. Indeed, Roth, by his own admission, said that he gave advice and support to numerous student groups.

On December 2, 1968, a meeting was scheduled between the Oshkosh administration and the parents of the suspended black students. Roth admitted dismissing his class in International Relations which was scheduled at the same time, and he encouraged his students to join him at the meeting. Three days later Dr. Raymond Ramsden, Vice-President of Academic Affairs, sent Roth a note indicating that he wanted to discuss this action with him. Roth refused to respond to the Vice-President's request.

Between the end of Thanksgiving recess and Christmas vacation, Roth was accused by the Oshkosh Administration of not teaching material pertinent to his International Relations course. Several students claimed in depositions that fifty to seventy-five per cent of the class time between these periods was devoted to discussing the black student riots and related matters. Roth freely admitted this, arguing that the Oshkosh events constituted a "microcosm of international conflict." Arthur Darken, Dean of Letters and Science and an international relations scholar, admitted this was a good analogy. But he maintained that Roth greatly overused what should have been an illustrative point in one lecture.

On Friday, December 20, 1968, the Wisconsin State University Board of Regents convened in special session to make a final decision on the academic status of the ninety-four suspended students in response to a court order issued by United States District Judge James Doyle.[3] Roth led a group of students and faculty in presenting a petition to the Board asking for the reinstatement of the ninety-four students. When the petition was being presented to the Board an incident allegedly occurred that compounded David Roth's problems at Oshkosh. He was accused of saying, "Here it is, you racist pigs." No administrator or faculty member interviewed at Oshkosh admitted to having heard Roth make the statement. Roth himself denied it. However, two members of the Board of Regents maintained this is what he said. Whether or not he actually made the statement is therefore unclear. As one high administrative official at Oshkosh stated, "I have heard from reliable sources that he did say it, and I have heard from equally reliable sources that he didn't say it."

At any rate, no mention of this particular allegation was made in the official memorandum from Dean Darken to President Guiles and Vice-President Ramsden which recommended that Roth not be retained.[4] Instead, Dean Darken emphasized the fact that Roth

[3] See Marzette v. McPhee, 294 F. Supp. 562 (1968).

[4] Dated January 28, 1969, and reprinted as Exhibit C in the Appendix to the appellant *State of Wisconsin's Brief* at pp. 120–126.

was scheduled for three classes on Friday, December 20, during which time he was in attendance at the Board meeting. He stated:

> . . . if this is to be overlooked or simply 'winked at' because Dr. Roth was casting himself in the role of a 'liberal spokesman' the door is opened to all professors to cut their classes whenever they believe one of their personal or social objectives would be served in this way. Faculty are engaged to teach and it is simply not acceptable that they fail to meet classes for such reasons as prevailed here.[5]

Roth admitted that he did not teach his classes on the day that the Regents were meeting in Oshkosh. However, he maintained he was absent on December 20 due to illness. He went instead to his office and the Board meeting because he thought that these demands on him would be less than in the classroom. The administration, needless to say, viewed this as a gross breach of professional ethics and responsibility.

Dean Darken was also disturbed by several public statements Roth made to the press. Darken said they "indicate a very unscholarly approach to the truth and the search for knowledge that make it doubtful he has the qualities of scholarship desirable in a faculty member." The Dean also indicated that Roth said: "Many of us feel that the authoritarian and autocratic structure of this university is no longer tolerable," and "The state universities will not be able to keep good professors if they are told they can't teach this or that in their classes." Darken argued that Roth never made any attempt to specify what was authoritarian and autocratic nor did he mention any instances where any faculty were told "what to teach or what not to teach."[6]

Furthermore, according to Dean Darken, Roth advised students not to go to an informational meeting to learn of the progress being made on the demands of the black students. He was reported to have said, "We won't talk to any Mickey Mouse committee." Darken concluded:

> If a college professor cannot be expected to encourage a rational approach to a problem of our day, who can be expected to do it? . . . What is involved here is not the freedom of the faculty member to explore competing views in search of the truth in his class or research but the use of unsubstantiated allegations of a grave nature in a tense and possibly inflammatory campus situation. This behavior is not consistent with what the University has a right to expect from a faculty member in the way of scholarship.[7]

Finally, Roth did not give a two-hour written final examination in his International Relations course for freshmen, which is required at Oshkosh, despite an official directive from the Vice-

[5] *Ibid.,* p. 121.
[6] Dean Darken's memorandum, pp. 122–123.
[7] *Ibid.*

President for Academic Affairs.[8] Instead, Roth used a group project which had been done earlier in the semester in lieu of a final. Dean Darken's memorandum stated:

> The final examination, especially in lower level and freshman courses serves an important purpose and it is not tolerable for a first year faculty member in one of his first teaching assignments to cavalierly decide he won't give a final examination to students and breach a major all-university policy that is in the interest of the students.[9]

PROCEDURES LEADING TO THE NON-RETENTION DECISION

The procedures leading to the non-retention of Dr. David Roth began on Dcember 17, 1968 when the Political Science Tenure Committee (composed of the department chairman, who was not tenured, and the four tenured members of the department) voted unanimously to retain all of the non-tenured faculty members, including Roth. Apparently, there were some reservations about retaining Roth, but the general feeling was that there wasn't sufficient evidence of misconduct to warrant non-retention at the time of the December 17 meeting which, of course, was prior to the December 20 incident at the Board of Regents meeting.

Prompted by the December 20 incident, however, as well as by some additional public statements made by Roth early in January, and also by his failure to give a final examination, Dean Darken asked the four tenured members of the department to meet in his office on Friday, January 24, 1969. At this time the Dean informed them of his recommendation not to retain Roth. He then told them, if they chose to do so, they had until 4:00 p.m. Monday, January 27, to reconsider their recommendation in light of Roth's actions since the December 17 meeting. On Monday the committee cast one vote for retention and two against it, with two abstaining. Roth was informed of his non-retention for the 1969–1970 academic year both by telephone and by registered letter on January 30.

DAVID ROTH IN THE FEDERAL COURTS

On February 14, 1969, through attorneys provided by the Wisconsin Chapter of the American Civil Liberties Union, David Roth filed suit in the Federal District Court for Western Wisconsin, Judge James Doyle presiding. In the complaint it was alleged that Roth's contract had not been renewed merely because he had exercised his constitutional rights of freedom of speech on matters of

[8] Vice-President Ramsden wrote, in a memorandum to all faculty, dated December 17, 1968: "Every class, with exceptions listed below, will end with a 2-hour final written examination to be given during the time arranged for it in the schedule. If you are of the opinion that a two-hour final written examination is inappropriate for a course not listed, please make this known to me by 4:00 p.m. Friday, December 20."

[9] Dean Darken's memorandum, p. 120.

university policy and practice. Furthermore, it argued that to refuse to renew his contract without providing him a statement of the charges made against him and an opportunity to respond to them at a formal hearing was a denial of his constitutional right to due process of law.

Judge Doyle unexpectedly held this case under advisement for a whole year, finally handing down a decision on March 12, 1970. Judge Doyle agreed with Roth's complaint and ordered:

> Substantive constitutional protection for a university professor against non-retention in violation of his First Amendment rights or arbitrary non-retention is useless without procedural safeguards. I hold that minimal procedural due process includes a statement of the reasons why the university intends not to retain the professor, and a hearing if the professor appears at the appointed time and place.[10]

He further stated that if the defendants, that is, the university officials, elected not to abide by the above order requiring a statement of reasons and a hearing, they

> . . . shall be required, on or before June 1, 1970 to offer the plaintiff a contract as a member of the faculty of the university for the academic year 1970–1971, on terms and conditions no less favorable to him than those contained in his contract for the academic year 1968–1969.[11]

The Wisconsin Attorney General applied to the Seventh Circuit Court of Appeals for a stay of execution of the lower court's decision pending appeal, which was routinely granted. The case was argued before the Seventh Circuit Court of Appeals on December 5, 1970. The Seventh Circuit Court issued its opinion on July 1, 1971, sustaining Judge Doyle's decision. Speaking for a divided court, Judge Thomas Fairchild agreed that a hearing and a statement of reasons were constitutionally required. He said:

> Although the principle announced by the district court applies by its terms to all non-retention decisions, an additional reason for sustaining application in the instant cases, and others with a background of controversy and unwelcome expressions of opinion is that it serves as a prophylactic against non-retention decisions improperly motivated by exercise of protected rights.[12]

Chief Circuit Judge F. Ryan Duffy dissented on the grounds that the decision would have the effect of making the federal courts the "final arbiters of all similarly situated cases." Duffy added:

> In my view, the state's interest in preserving a workable system of tenure which includes, almost by definition the ability to select freely and maturely its non-tenured teaching personnel, far outweighs any expectancy which the plaintiff David Roth might have had in continued employment at Wisconsin State University . . . I further believe that the majority's

[10] 310 F. Supp. 972 (1970), 978.
[11] *Ibid.*, p. 980.
[12] 446 F. 2d. 806 (1970), Circuit Judge Otto Kerner sided with Judge Fairchild.

> holding is both unprecedented and represents an unwarranted intrusion of the Federal Judiciary into state educational systems.[13]

The stage was set, then, for an appeal to the United States Supreme Court, and the Board of Regents decided almost immediately to go ahead with an appeal.

THE SUPREME COURT DECISION

The United States Supreme Court granted *certiorari* on October 26, 1971.[14] Oral arguments in the case were presented on January 18, 1972, and a decision was handed down on June 29, 1972.[15]

The opinion of the court was delivered by Justice Stewart and joined in by Justices White, Blackmun, and Rehnquist. Chief Justice Burger filed a concurring opinion. Justices Douglas, Brennan, and Marshall dissented. Justice Powell did not participate in the decision.

Stewart's opinion began with a brief statement of the facts, a review of applicable state statutes, and a summary of the lower court opinions. Clearly, according to Stewart's opinion, Roth did not have any tenure rights to continued employment. At that time all teachers in the Wisconsin State University System were governed by statutory tenure which said that a teacher acquired tenure after being employed continuously for four years.[16] A non-tenured teacher under Wisconsin law was entitled to nothing more than his initial one-year appointment. State statutes definitely gave university officials complete discretion over whether or not to renew a non-tenured teacher's contract. While the Board of Regents rules did not provide any protection for a non-tenured teacher whose contract was not renewed, the Court indicated that they did provide for a hearing and a statement of reasons if a teacher was dismissed during the school year before the term of his contract was up.[17]

According to the Court, the main issue was whether Roth "had a constitutional right to a statement of reasons and a hearing on the University's decision not to rehire him for another year. We hold that he did not."[18] The remainder of the opinion is devoted to a statement of the rationale for this conclusion. While the Court did not disagree with Judge Doyle's standard of simply weighing the interest of the plaintiff in having his contract renewed against the university's interest in refusing to renew his contract, it held that it was necessary to go beyond this. Before weighing the inter-

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[13] *Ibid.*
[14] 404 U.S. 909 (1971).
[15] 408 U.S. 593 (1972).
[16] 1969 *Wisconsin Statutes,* Chapter 37.31.
[17] 408 U.S. 567 (1972).
[18] *Ibid.,* 569.

ests, the Court held that it was necessary to first determine "the nature of the interest at stake."[19]

In order to determine "the nature of the interest at stake" the Court specified that it had to be decided whether or not the interest was specifically protected under the Fourteenth Amendment's protection of liberty and property. The Court first considered the liberty aspect. It stated that liberty included:

> not merely freedom from bodily restraint but also the right of the individual to contract, to engage in any of the common occupations of life, to acquire useful knowledge, to marry, establish a home and bring up children, to worship God according to the dictates of his own conscience, and generally to enjoy those privileges long recognized . . . as essential to the orderly pursuit of happiness by free men.[20]

If the university had made charges against him which could seriously damage his position in the community by implying, for example, that "he had been guilty of dishonesty and immorality," then, the Court concluded, that would have been a completely different situation. The Court would also have disapproved if the university had in some way placed a stigma on him that took away his freedom to continue engaging in his profession.[21] However, the Court decided that the university had done neither of these things. In finalizing its discussion of the liberty issue the Court held:

> Hence, on the record before us, all that clearly appears is that the respondent was not rehired for one year at one university. It stretches the concept too far to suggest that a person is deprived of 'liberty' when he simply is not rehired in one job but remains as free as before to seek another.[22]

The Court also maintained that the plaintiff had not proven that the decision not to renew his contract was based on his free speech activities. The Court stated: "Whatever may be a teacher's rights of free speech, the interest in holding a teaching job at a state university, *simpliciter,* is not itself a free speech interest."[23]

Next, the Court's opinion discussed the property issue, admitting that an individual's property rights or interests may take a wide variety of forms. The Court cited several cases defining those property interests. For example, the Court said that it had held that welfare benefits are a property interest safeguarded by procedural due process.[24] Similarly, the Court stated that it has held that public college professors cannot be dismissed from their positions

[19] *Ibid.,* 570–571.
[20] *Meyers v. Nebraska,* 262 U.S. 390 (1922), 399, cited by Justice Stewart at 408 U.S. 564 (1972), 572.
[21] 408 U.S. 564 (1972), 573–574.
[22] *Ibid.,* 575.
[23] *Ibid.*
[24] *Ibid.*

without procedural due process[25] and that they cannot be summarily dismissed during the terms of their contracts.[26] Moreover, the Court has maintained that even a substitute teacher who had been employed two months could not be dismissed because of her refusal to sign a loyalty oath.[27] From these decisions, the Court argued that a definition of property interests emerged:

> To have a property interest in a benefit, a person must have more than an abstract need or desire for it. He must, instead, have a legitimate claim of entitlement to it. It is a purpose of the ancient institution of property to protect those claims upon which people rely in their daily lives, reliance that must not be arbitrarily undermined. It is a purpose of the constitutional right to a hearing to provide an opportunity for a person to vindicate those claims.[28]

The Court then made the distinction that property interests are not created by the Constitution but by laws or rules enacted or understandings promulgated by states. Hence, the plaintiff-respondent's property interest in having his contract renewed at Oshkosh State University was created and limited by the terms of his appointment which specifically secured his interest in employment from September 1, 1968 to June 30, 1969.[29] Indeed, the Court indicated the terms "made no provision for renewal whatsoever." Thus, it concluded its assessment of the property interest and the entire opinion by saying:

> In these circumstances, the respondent surely had an abstract concern in being rehired, but he did not have a property interest sufficient to require the University authorities to give him a hearing when they declined to renew his contract of employment.
>
> IV
>
> Our analysis of the respondent's constitutional rights in this case in no way indicates a view that an opportunity for a hearing or a statement of reasons for non-retention *would*, or *would not*, be appropriate or wise in public colleges and universities. For it is a written Constitution that we apply. Our role is confined to interpretation of that Constitution.
>
> We must conclude that the summary judgment for the respondent should not have been granted, since the respondent has not shown that he was deprived of liberty or property protected by the Fourteenth Amendment.[30]

DISSENTING AND CONCURRING OPINIONS IN *ROTH*

Justices Brennan and Marshall filed separate dissenting opinions. They argued for a broader definition of liberty and property, saying that both plaintiffs were entitled to a statement of reasons and

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[25] *Slochower v. Board of Education,* 350 U.S. 551, cited at 408 U.S. 564 (1972), 577.
[26] *Weiman v. Updegraff,* 344 U.S. 183, cited at 408 U.S. 564 (1972), 577.
[27] *Connell v. Higginbotham,* 403 U.S. 207, cited at 408 U.S. 564 (1972), 577.
[28] 408 U.S. 564 (1972), 577.
[29] 408 U.S. 564 (1972), 577–578.
[30] *Ibid.,* 578–579.

a hearing on the disputed issues.[31] Justice Douglas in a more lengthy opinion argued that a statement of reasons and a hearing were necessary to guarantee individual rights against arbitrary action. He stated:

> When a violation of First Amendment rights is alleged, the reasons for dismissal or for non-renewal of an employment contract must be examined to see if the reasons given are only a cloak for activity or attitudes protected by the Constitution.[32]

Chief Justice Burger wrote a concurring opinion for the express purpose of emphasizing one central point that he felt had been obscured in the majority opinion. That point was that disputes between a state educational institution and one of its teachers is a matter of state concern and state law. Burger raised the doctrine of abstention, as he has done in many other opinions since being appointed to the Court. He concluded:

> If relevant state contract law is unclear, a federal court should, in my view, abstain from deciding whether he is constitutionally entitled to a prior hearing, and the teacher should be left to resort to state courts on the questions arising under state law.[33]

ASSESSMENT OF *ROTH* DECISION

The *Roth* case was an extremely complicated controversy arising out of unusually explosive circumstances. As is true in any emotionally-charged crisis, whether it be an automobile accident, a robbery, or a riot, reasonable men can view the same factual circumstances and come to completely opposite conclusions. This was certainly true of the *Roth* case, and it became more and more apparent with every individual interviewed, and every document, report, newspaper article, or legal brief. A deep schism was created over the personality of David Roth between those who regarded him as politically naive and those who saw him as a political revolutionary.

To the people of Oshkosh, Wisconsin, Roth presented himself as a true revolutionary bent on the complete destruction of the university and the American political system. His public statements, which were widely published in the press in Oshkosh and in Madison and Milwaukee, lent a good deal of substance to that collective impression.

One faculty member characterized Roth as a "bright, personable, abrasive bastard." Another observed that:

> when he set his mind to it he could be very charming, but when he got fired-up he was a real fireeater. When there was controversy he seemed

[31] 408 U.S. 564 (1972), 587–592, 604–605.
[32] *Ibid.*, 579.
[33] *Ibid.*, 582.

> to thrive on the smoke of the battle. He had a sort of 'Dr. Jekyll–Mr. Hyde personality.'

Roth characterized himself as having been "very immature and naive" throughout the whole Oshkosh crisis. He felt that "speaking out against injustice" was his responsibility as a member of the academic community:

> My non-retention resulted from a personality conflict because I embarrassed the administration by criticizing their policies and their lack of sensitivity to blacks. This was perceived by them as disloyalty to the university and being in favor of violence.

During the four hours this writer spent with Roth, he certainly gave the impression of being naive and trusting. For example, in the middle of the evening he suddenly announced that he had to leave to meet a friend but that I was free to go through all of his files on my own. He was gone for over two hours. Needless to say, this was quite surprising in that I was a total stranger to him. Throughout the interview he came across as a very personable, calm, and likable individual. Indeed, the evening was a very pleasant one.

However, if Roth had been more politically astute he could very easily have taken many of the same stands, while remaining within the bounds of professional ethics and responsibility as well as civil discretion. In fact many of the things that he did and said (and allegedly did and said) demonstrate such incredible naivete that one might begin to question whether he might not have been deliberately projecting this as a facade in the hope that it might advance his cause.

After all, David Roth was definitely not a provincial person from the homogeneous socio-economic political environment of a rural community. He had graduated from Claremont Men's College, a small liberal arts college with a reputation for academic excellence located in Claremont, California (on the eastern edge of Los Angeles County). He had gone to the University of California Law School at Berkeley for two years. He had lived in cosmopolitan San Francisco, while obtaining a master's degree from San Francisco State College. He had traveled extensively in the Philippines and the Far East, while doing research for his doctoral dissertation at the Claremont Graduate School, Claremont, California. Finally, he had spent a year in Berkeley, California doing research, prior to coming to Oshkosh. With this kind of background he should have been able to discern the legitimate modes and boundaries of dissent in a more sophisticated manner than he demonstrated in the 1968–1969 academic year at Oshkosh.

Whatever David Roth's intent was, however, an extensive investigation of the circumstances and events surrounding and leading up to the federal litigation in the *Roth* case leaves little doubt that the Oshkosh administration acted in a reasonable manner. They made the decision not to renew Roth's contract mainly because this was the most rational action they could take. Had they allowed Roth to remain on the faculty, they would have been taking a calculated risk of his escalating his protest actions and thus inflaming an already dangerous situation. Roth's actions in dismissing classes on two separate occasions in order to pursue his own political objectives, his extensive use of the classroom podium to discuss irrelevant material, his failure to give a final examination, and his refusal to honor a request from the Vice-President of Academic Affairs for a meeting all forced the Oshkosh administration to refuse to renew his contract.

IMPLICATIONS OF THE *ROTH* DECISION

The United States Supreme Court's decision in *Roth* was characteristic of the reasonable restraint the Burger Court has demonstrated in matters of federal-state relationships. Its stance regarding judicial activism is quite different from that of the Warren Court. If this case had come before the Court one or two years earlier, a vastly different decision would probably have been reached. However, the majority opinion rightly recognized the difficulties likely to be created when a federal court involves itself in matters that might more prudently be left to the states.

One problem that would probably have occurred if the lower court decision in *Roth* had been sustained is that an administrator would be extremely reluctant to decide against renewing an individual's contract if he knew that this would oblige him to file formal charges and go through a formal hearing. By the nature of the case the definition of good teaching is rather subjective and precise documentation of bad teaching is very difficult. After all, a teacher can always be defended by such arguments as (1) every instructor has some bad days, (2) he was not feeling well, (3) some students think he is wonderful, or (4) whatever his faults, he is improving. The burden of proof in a formal, adversary hearing procedure thus falls on the administrator instead of the teacher. As a practical matter probably very few contracts would go unrenewed given this kind of situation. How many administrators could reasonably be expected to non-retain a professor when the benefits of his non-retention might very well be overshadowed by the bitter rhetoric and controversy caused by the hearing? If, as a matter of policy, an administrator did decide to proceed with hearings under such circumstances, he would probably have to keep a dossier on every faculty member, dating and documenting every incident that might conceivably bear upon a teacher's competence. This is a prospect that would not be welcomed by many, especially not by those who are the strongest advocates of extensive hearing procedures.

Moreover, if *Roth* had been upheld, faculty members who would ordinarily be releasable would have an incentive to create ambiguous and volatile situations which would make it very difficult, if not impossible, to remove them. A dissident faculty member could, for example, set himself up as an outspoken defender of a minority group in order later to be able to accuse the administrators of being racist or bigoted for not renewing his contract, and in many respects Roth did exactly that.

Justice Douglas' dissenting opinion in Roth is a classic example of the limits of adjudication arising from our judicial adversary system. The Court simply does not have the required investigatory powers similar to those available to state (and national) legislatures. For example, his opinion flippantly glosses over the events and circumstances in the case that could not be covered adequately in the appellate briefs and oral arguments. This is how he characterized Roth's behavior:

> Though Roth was rated by the faculty as an excellent teacher, he had publicly criticized the administration for suspending an entire group of 94 black students without determining individual guilt. He also criticized the university's regime as being authoritarian and autocratic. He used to discuss what was being done about the Black episode; and one day, instead of meeting his class, he went to the meeting of the Board of Regents.[34]

As a result, he concluded that the district and circuit court decisions should be sustained.

The problem with his capsulization is that is grossly oversimplifies a very complex set of circumstances and events. It completely ignores the intensity and the magnitude of Roth's actions and the context in which they occurred. The fact that Roth attended a Board of Regents meeting is portrayed as a petty irregularity instead of the blatant breach of professional responsibility that it seemed to be according to most reports. Moreover, it ignores the other occasion when he failed to meet his classes, that is, when he attended the meeting between the Oshkosh president and the parents of the black students. It also fails to note the fact that he violated an explicit university rule by failing to give a written final examination. And it fails to mention his insubordination when he cavalierly spurned the request to meet with his Vice-President for Academic Affairs.

Finally, if the lower courts' decisions had been sustained, the traditional distinction between tenured and non-tenured faculty

[34] 408 U.S. 564 (1972), 576.

would have been obliterated. Instant tenure, with all its ensuing rights and privileges, would have been created for all faculty merely upon signing an initial employment contract. Such a rule would have been in direct contradiction of accepted practice on the part of 1,080 colleges and universities with 300,000 faculty members and 6,000,000 students.[35] It would have meant that all non-tenured, non-retained faculty members could have appealed their cases.

The amount of administrative and faculty time that would have had to go into investigating, documenting, and holding hearings would have been staggering. In the Wisconsin State University System, for example, there were some 206 non-tenured faculty contracts that were not renewed for the 1970–1971 academic year alone.[36] The cost of paying the investigating administrators' salaries as well as the legal expenses incurred would have been overwhelming. The federal courts, of course, would not have ever had to face these particular consequences.

In short, the *Roth* case raised this basic question: is there any rational justification for distinguishing between the rights enjoyed by tenured faculty and those to which non-tenured faculty should be entitled? Why should one group of faculty members have greater rights than another? In criminal law the granting of certain procedural rights to one group of alleged criminals, while granting a different set to another, would be considered unconstitutional because it would be a denial of "the equal protection of the law." In *Roth* Judge Doyle and the Seventh Circuit Court of Appeals said in effect that there was really no rational basis for making such a distinction, although they never specifically discussed whether the distinction was constitutionally valid or even rationally defensible. By so doing they seemed to make educational disciplinary cases more closely akin to criminal proceedings and, in the process, take away the right of a professional group to organize and regulate their profession according to their own free choice.

The primary reason for differentiating between the rights of tenured faculty and non-tenured faculty is, of course, that only performance or experience can provide a sound basis for the presumption by an institution that a new teacher has attained a degree of excellence deserving of tenure. Initial appointments cannot ordinarily be made on grounds providing sufficient assurance that a person will reach this standard of excellence. For this reason it

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[35] *Amici Curiae* in support of the *State of Wisconsin's Petition for a Writ of Certiorari*, p. 2, written by the Honorable Robert W. Warren, Attorney General of Wisconsin, Assistant Attorney General Charles A. Bleck, and Assistant Attorney General Robert D. Martinson, October Term, 1971, all at 114 East, State Capitol, Madison, Wisconsin, 53702.

[36] *Ibid.*, p. 13.

is inherently unfair to assume that a non-retention decision, made early in an instructor's affiliation with an institution, represents a denial of academic freedom rather than a reasonable assessment of his ability as a teacher and a scholar.[37]

If the Supreme Court had affirmed the *Roth* decision, the federal judiciary would have been allowed to expand its role in school disciplinary cases, and where some federal judges might have gone from this point, if given encouragement, is anyone's guess. Public policy would have gradually ceased to reflect the wishes of the people as expressed through their elected representatives on state and local governing boards. Instead, it would have reflected the judgment of a few appointed federal judges far removed from the express wishes of the people.

Fortunately, the Supreme Court made a decision in *Roth* that promises to arrest the continued expansion of the federal judiciary in educational disciplinary cases. The Court seems to be moving in the direction of giving the job of policy-making back to state and local governments not only in the area of educational discipline but also in other areas where continued expansion of judicial policy-making occurred during the Warren Court era.

There is no doubt that local and state governing boards, as well as the voters who either directly or indirectly select them, occasionally make decisions that by most rational standards of measurement are wrong. But in a democratic republic such as the United States, do they not have the right to be wrong? And do they not have the right to be free from having a decision superimposed on them by federal courts against deliberate policy decisions they have made? Then, too, careful analysis of the two lower court decisions in the *Roth* case demonstrates that it is at least an open question whether they will be any less reasonable in their decisions than some federal judges have been.

To the extent that federalism has been challenged by the lower federal court decisions in *Roth* and in numerous other educational disciplinary cases at both the secondary and higher educational levels, federal judges (and to some extent the legal profession itself) have done a disservice to American society. They have raised relatively minor injustices into constitutional issues which have strained the federal system. If the Burger Court had not reversed the district and circuit court's decisions in *Roth* and hence reversed the trend established in educational disciplinary cases in the later 1960's, the state and local governments' ability to control educational policy in their own schools and colleges would have continued to decrease. Further erosion of state control of educa-

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[37] William S. Van Alstyne, "Tenure, A Summary, Explanation, and Defense," *AAUP Bulletin,* LVII (September, 1971), pp. 332–333.

tional disciplinary matters could have contributed to the death of federalism which the framers of the Constitution believed vital to the cause of freedom.

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ADDENDUM

After this paper went to press, a federal court jury in Madison, Wisconsin, on November 9, 1973, awarded David Roth, now an assistant professor of political science at Purdue University, $6,746 in damages because, in their judgment, his constitutional rights of free speech were violated. The damages were assessed against Oshkosh administrators, President Roger Guiles, Vice-President Raymond Ramsden, Dean Arthur Darken, and two members of the Oshkosh Political Science Tenure Committee, David Chang and Charles Goff, all of whom participated in the decision not to retain Roth.

It must be understood that Roth was awarded these damages in a civil suit which he filed after the United States Supreme Court in 1972 had ruled on the procedural question that the due process clause of the Fourteenth Amendment did not require that a non-tenured professor be given a hearing in a non-retention proceeding. Hence, it must be emphasized that the civil suit for damages, concerning the substantive question as to whether Roth's constitutional right of free speech had been violated, has no direct legal bearing on the procedural decision handed down by the Supreme Court.

In spite of the jury's verdict to the contrary, I must respectfully disagree and stand by my own conclusions which are based upon an extensive investigation of the events and related constitutional issues.

WILD SOILS OF THE PINE–POPPLE RIVERS BASIN[1]

Francis D. Hole
University of Wisconsin—Madison
and
Wisconsin Geological and
Natural History Survey

The preservation of wild rivers involves the protection of the surrounding "wild" soils. The usage of the term is new as applied to soils, but the concept is old. Wild soils are those which still function as integral parts of their native ecosystems. They have not been domesticated through drastic human manipulation of plant and animal populations and of the soils themselves, with resulting modifications in local cycling of nutrients and water. It is noteworthy that modern soil classification does not adequately recognize the difference between a wild soil and its cultivated counterpart, both of which are given the same name! This is an ecological error, which may be corrected by recognizing wild and domesticated variants of soils.

The purpose of this paper is: 1) to summarize and interpret, in the context of the ecosystems of the Pine–Popple Rivers Basin, field and laboratory data obtained on soils of the area by the Wisconsin Geological and Natural History Survey, particularly during the study in Florence County in 1958–1961 (Hole *et al.*, 1962); and 2) to delineate some future studies of wild soils to which the Basin is well suited.

LITERATURE REVIEW AND METHODS

The Pine–Popple Rivers Basin has been clearly delineated in maps recently published by Mills (1972) and Becker (1972), showing what portions of Forest and Florence Counties are included in it. Table 1 traces changes in terminology for the five general kinds of soils that have been recognized in the Basin since 1885. For an explanation of the technical classification terms given in parentheses for 1962 in Table 1, and throughout Table 2 and Fig. 2, the reader is referred to the new U.S.D.A. soil classification scheme (Soil Conservation Service, 1973). The terms used in the legend of Fig. 1 of this paper are simplified.

[1] This is paper No. 9 in a series of studies of the Pine–Popple Wild Rivers area of northeastern Wisconsin; the publication of which began in volume 60 of these Transactions.

TABLE 1. SOME DESIGNATIONS OF FIVE GENERAL KINDS OF SOILS IN THE PINE-POPPLE RIVERS BASIN

1882[1]	1916[2]	1921[3]	1962[4]	Figure 1 of this paper
Sandy soils	2. Light sandy soil (Norway, white, jack pines and poplar)	Vilas stony sand Vilas fine sand	12 Vilas, Pence and associated soils (Typic Haplorthods)	Sa Sandy soils
Sandy loams	3. Heavy sandy loam (Birch, hemlock, maple, white and Norway pines)	Kennan fine sandy loam Antigo fine sandy loam	3, 4, 9 Pence, Iron River, Ahmeek, Stambaugh and associated soils (Typic and Alfic Haplorthods)	LA and LE Loamy soils with and without rock outcrops
Clayey loams, lighter varieties	4. Silt loam with well drained subsoil (Hardwoods and white pine)	Kennan silt loam Antigo silt loam	1, 2, 6, 7 Goodman, Fence, Stambaugh and associated soils (Alfic Haplorthods)	Si Silty soils
	5. Silt loam with heavy subsoil (White pine, hardwoods)	Superior loam	5 Hibbing, Ubly and associated soils (Typic Eutroboralfs)	C Clay soils
Humus soils (mainly muck and peat)	9. Peat and muck (Largely open grass marshes, partly wooded with spruce and tamarack)	Peat	15, 16 Peat and muck associated soils (Typic Borosaprists and Borohemists)	P Peat

[1]Chamberlin, 1883 (Soil map of Wisconsin, 1882).
[2]Whitson *et al.*, 1916 (Soil map of Northeastern Wisconsin).
[3]Whitson *et al.*, 1921 (Soil map of Northern Wisconsin).
[4]Hole *et al.*, 1962 (Soil map of Florence County, Wisconsin).

TABLE 2. A CLASSIFICATION OF MAJOR SOIL SERIES IN THE PINE–POPPLE WILD RIVERS BASIN[1]

Order	Suborder	Great Group	Subgroup	Series [2]
Alfisols (high base status forest soils)	Boralfs (common northern Alfisols)	Eutroboralfs (fertile Boralfs)	Typic (typical)	Hibbing (on red clay till)
			Typic (typical)	Ontonagon (on red clay lake beds)
			Aquic (somewhat wet)	Rudyard (on red clay lake beds)
Entisols (recently formed soils)	Orthents (common Entisols)	Udorthents (humid climate Orthents)	Typic (typical)	Emmert (A1 horizon on sand and gravel)
Histosols (organic or tissue soils)	Fibrists (fibrous Histosols)	----------	----------	(peat)
	Hemists (half-way decomposed Histosols)	----------	----------	(peaty muck)
	Saprists (decomposed Histosols)	----------	----------	(muck)
Inceptisols (Embryonic soils)	Aquepts (wet Inceptisols)	Haplaquepts (simple Aquepts)	Aeric (sometimes aerated)	Bergland (on red limey clay lake beds)
			Mollic (rather deep, fertile A1)	Bruce (on gray limey loamy lake beds)
			Aeric	Pickford (on red limey clay till)

TABLE 2 (CONTINUED)

Order	Suborder	Great Group	Subgroup	Series[2]
Spodosols (soils with subsoil accumulations of humus and iron)	Orthods (common Spodosols)	Haplorthods (simple Orthods)	Typic (typical)	Au Train (Wallace) (with maximal Bhir on sand) Crivitz (loamy sand on sand) Omega (A1/Bhir on sand) Pence (sandy loam on sand and gravel) Vilas (A2/Bhir on sand)
			Alfic ("double" profile)	Bohemian (silt loam on brown limey loamy lake sediments) Fence (silt loam on lake-laid silts) Goodman (silt loam on red loamy till) Manistee (sandy on limey red clay till) Menominee (sand on limey loam till) Padus (sandy loam on sand and gravel) Stambaugh (loam on sand and gravel) Superior (shallow loam on limey red clay lake beds) Ubly (Menominee; fine sandy loam deeply leached variant)
		Fragiorthods (Orthods with fragipan subsoil)	Typic	Ahmeek (loam on red till shallow to iron formation bedrock)
	Aquods (wet Spodosols)	Haplaquods (simple Aquods)	Alfic ("double" profile)	Brimley (silt loam on brown loamy lake sediments) Tipler (Gaastra) (silt loam on lake-laid silts)

[1]For further information see Buol *et al.* (1973) and Soil Conservation Service (1974).
[2]In this table the popular term "limey" is used in place of the technical terms "dolomitic" and "calcareous".

Field methods used were those for general or reconnaissance soil mapping. These are described in the Soil Survey Manual (Soil Survey Staff, 1951). Soils were observed at intervals of about one half to two miles. Laboratory analyses are reported elsewhere (Hole *et al.*, 1962).

Bouma and Hole (1971) presented evidence that two portions of a body of soil may behave very differently, where one portion is undisturbed under native vegetation and the other is managed for agricultural purposes. "Management-induced structural changes can strongly alter hydraulic properties of a soil. These changes may be of sufficient magnitude and continuity to consider recognition of hydraulic soil phases of established soil series. . ."

SOILS AND SOILSCAPES OF THE PINE–POPPLE RIVERS BASIN

Soils

The soils occupy the area of the "vast unbroken forest" lying on either side of the "thin blue thread" of each wild river (Mills, 1972). Of the forty-two kinds of soils (classified at the soil series level) and two kinds of miscellaneous land types (Alluvial soils and Granitic Rockland) described in the soil survey report for Florence

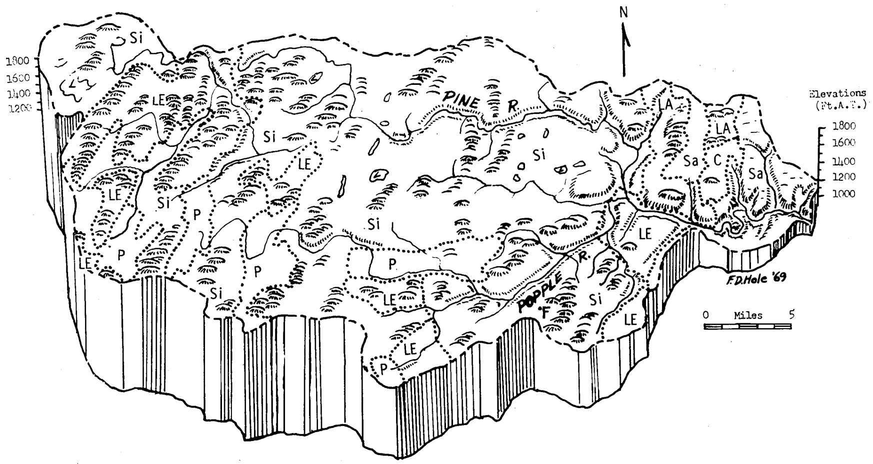

FIGURE 1. General soil map and block diagram of the Pine-Popple Wild Rivers Basin. Legend: C = clayey soils (Hibbing and Ontonagon); F = location of the village of Fence; LA = loamy soils including rock outcrops and Ahmeek loams; LE = loamy soils including Pence and Iron River loams and sandy loams; P = peat; Sa = sandy soils (Omega, Vilas); Si = silty soils (Stambaugh, Goodman, Fence, Bohemian). Dotted lines are soil boundaries adapted from Hole *et al.*, 1968. Large lakes are labeled *L.*

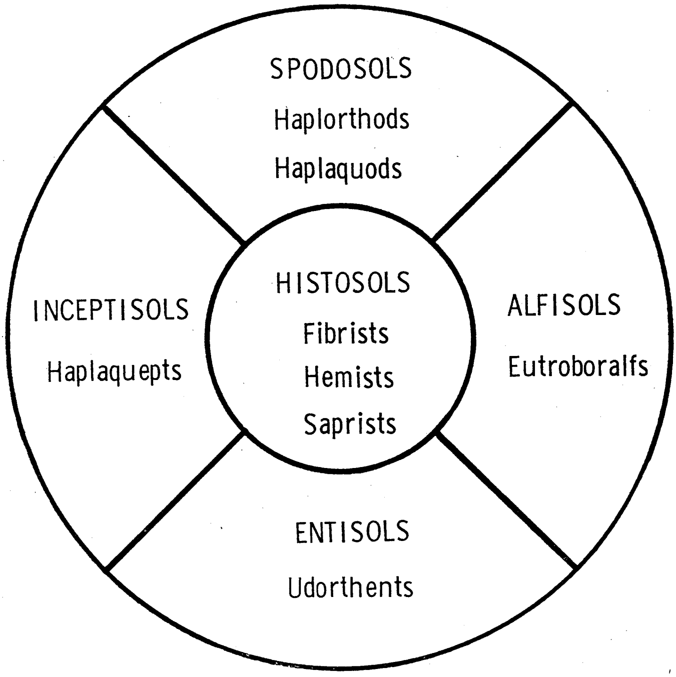

FIGURE 2. A classification chart for major great groups of soils in the Pine-Popple Wild Rivers Basin. The Haplorthods, Eutroboralfs and Udorthents are well drained members of their respective orders. Haplaquods, Haplaquepts and all Histosols are poorly to very poorly drained under natural conditions. See Table 2.

County, twenty-six soils (Table 2 and Fig. 2) and one land type are shown in Figs. 3 through 6. Nineteen of these soils are Spodosols (Podzols), which essentially consist in cross-section (profile view as shown in Fig. 6 for Vilas, Crivitz, Pence, Hiawatha, and Au Train soils) of four main horizons (layers): surface organic horizons (the O1 horizon is forest litter; the O2 is humus); a bleached pale mineral topsoil (A2 or albic horizon); a dark brown subsoil (Bhir or spodic horizon enriched in humus and iron) and yellowish brown to reddish brown glacial drift (C horizon: initial material). Wetland soils include peats (Histosols) and poorly drained mineral soils (Aquepts, Aquolls) which have black topsoil (A1) and grey (anaerobic and gleyed) subsoil. Some clayey soils (Gray Wooded soils: Eutroboralfs), including the Ontonagon and Hibbing series, have a subsoil enriched in clay (Bt or argillic horizon) instead of iron and humus.

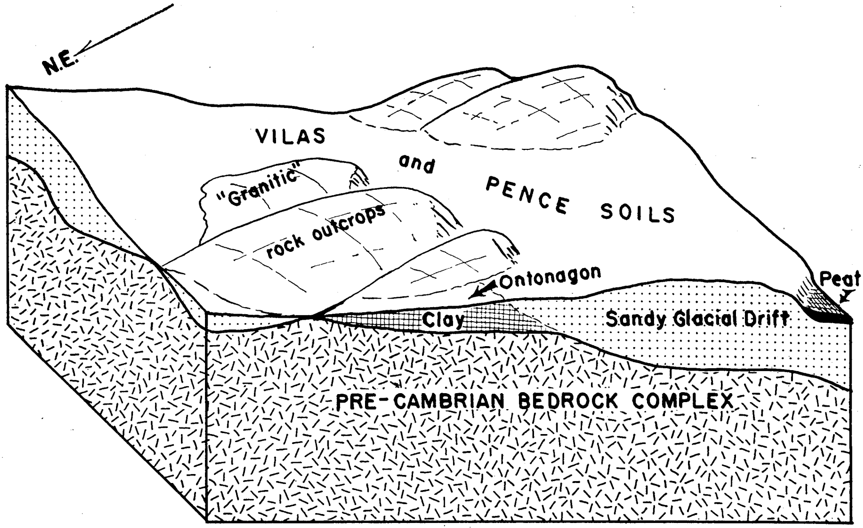

FIGURE 3. "Granitic" rock outcrops smoothed by the glacier, and filled between with loose soil material in LA, Sa and C regions of Fig. 1, in eastern portions of the Basin. The forest cover on these wild soils is not shown. (Fig. courtesy of the Wisconsin Geological and Natural History Survey.)

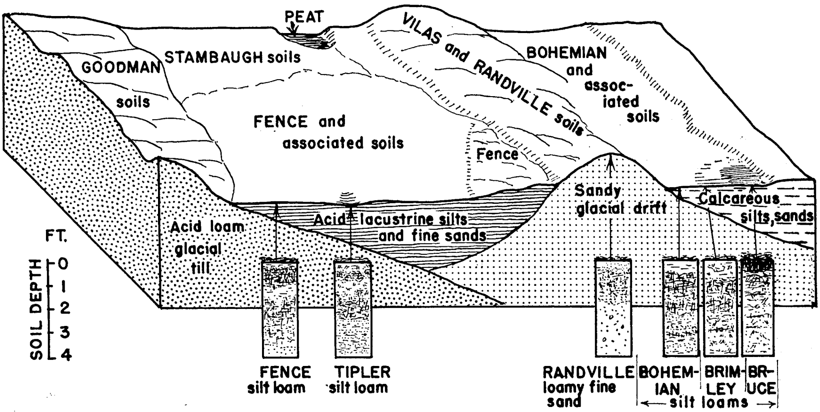

FIGURE 4. Silty soils (Si in Fig. 1) and sandy soils (Sa) of the Pine-Popple Wild Rivers Basin. Goodman silt loam is over glacial till, Stambaugh silt loam is on glacial outwash sand and gravel, Fence (and Tipler) silt loam on acid glacial lake beds, and Bohemian (and Brimley and Bruce) silt loam on calcareous lake beds; Vilas sand (and associated Randville) on deep outwash sands. The forest cover on these wild soils is not shown. The unlabeled upland on the extreme right is occupied by Ontonagon soils in this idealized sketch. (Fig. courtesy the Wisconsin Geological and Natural History Survey.)

It is interesting that the Basin contains many upland soils that are "hybrids", that is consisting of a Spodosol (Podzol) over a Eutroboralf (Gray Wooded) all in a single soil profile (Beaver, 1966). The horizon sequence in these "double" soil profiles is typically: O1, O2, A2, Bhir, A′2, B′t, C. The prime symbol (′) in the fifth and sixth horizons indicates that they are in the second or lower sequence. These two horizons are commonly fragipan horizons in the Pine–Popple Rivers Basin. The term fragipan (Olson and Hole, 1967) denotes compactness and resistance to water movement and root penetration. Double soil profiles (bisequal soils) with two light colored A2 horizons and two somewhat dark B horizons are shown in Figs. 4, 5 and 6 for soils named Fence, Tipler, Bohemian, Brimley, Superior, Ulby, Padus and Stambaugh. Theories about the formation of the soils are described elsewhere (Hole *et al.,* 1962; Buol *et al.,* 1973). Soil profiles, like those illustrated in the sketches, took thousands of years to form and represent an impressive environmental record. In deciphering this record, researchers look for evidence of the influence on soil of different forest types and climates, past and present, as discussed by Milfred *et al.* (1967) and Buol *et al.* (1973).

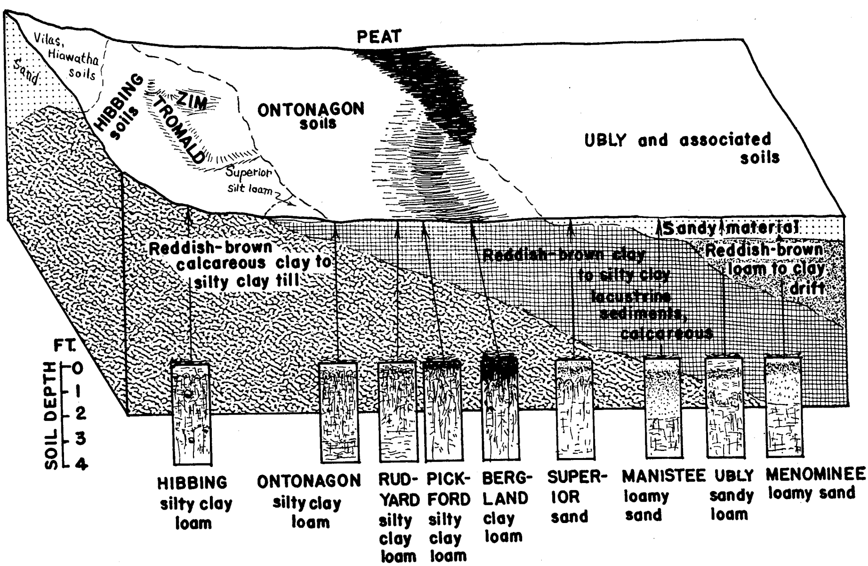

FIGURE 5. Clayey soils (C of Fig. 1) include Hibbing (on glacial till) and Ontonagon (on lake clays) with associated more poorly drained soils (Zim, Tromald; Rudyard, Pickford, Bergland). Where sandy coverings occur, Superior and associated sands and loamy sands are found. Vilas and Hiawatha sands are very deep (Sa of Fig. 1). The forest cover on these wild soils is not shown. (Fig. courtesy the Wisconsin Geological and Natural History Survey.)

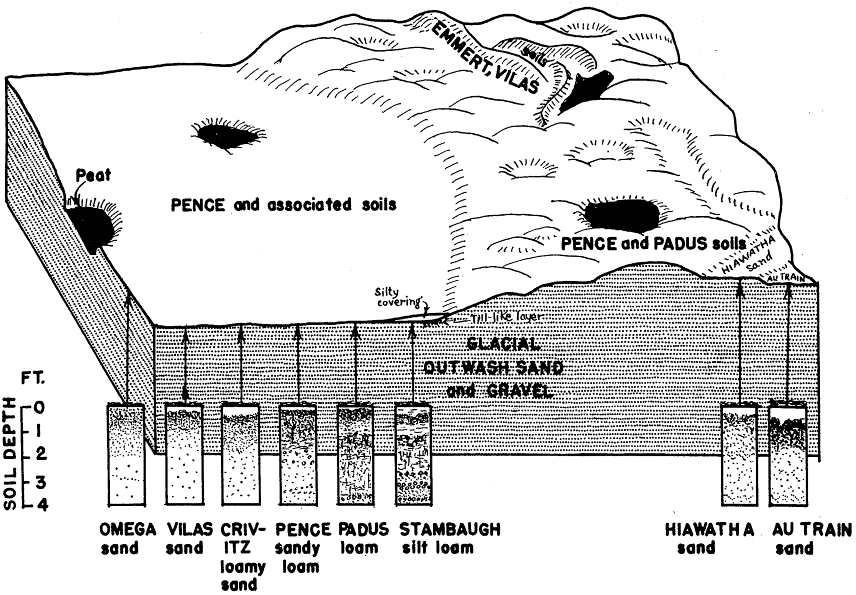

FIGURE 6. Loamy soils (LE, Fig. 1) are chiefly Pence sandy loam and the deeper Padus loam, with peat (P, Fig. 1) in deep kettles; and Vilas sand and Emmert gravelly sandy loam on esker ridges (of which there are about 200 in the Pine-Popple Basin). The forest cover on these wild soils is not shown. (Fig. courtesy the Wisconsin Geological and Natural History Survey).

Soilscapes

Soils are observed not only in the two-dimensional exposures called soil profiles, but also in geographic bodies and patterns of soil bodies on the landscape. A soilscape is the portion of a landscape consisting of the soils (Buol *et al.,* 1973). Fig. 1 shows in a very general way the arrangement of major soil groupings in the Pine–Popple Rivers Basin. The eastward change that Mills (1972) observed from the canoe, from "gravelly, richer soils of the upper river . . . to poor sand in the lower stretches" is indicated in the Figure by the dotted boundary between silty (Si) or loamy (LE) soils and sandy (Sa) soils. Soilscapes are shown in much greater detail in the idealized sketches of Figs. 3 through 6. Throughout the Basin droughty soils (such as Vilas and Emmert) and wetlands (such as Bergland and Bruce mineral soils and peat) are typically in close proximity (within a mile or less). Tree-tip mounds and associated pits are common microtopographic features in the forest (Gaikawad and Hole, 1961).

Factors of soil formation. The bedrock of the Basin consists of Precambrian volcanic and metamorphic rocks, some of which are exposed in the river channel bottom, as noted by Mills (1972). Glacial drift as much as 250 feet thick was deposited over the bedrock by continental glaciers, the last of which melted away from the Basin about 11,000 years ago or soon thereafter (see Bryson and Wendland, 1967). Coarse wind-blown silt was laid down in a blanket as much as a foot or two thick locally. Land forms include moraines, drumlins, eskers, outwash and lacustrine plains. Since glaciation, soils have formed from these materials under shifting continental climatic zones and biotic communities.

The biotic factor has been the most dynamic. Coniferous and mixed forest plant communities and associated fauna have left their impress on the soils of the Basin, as Wilde *et al.* (1949) and Hole *et al.* (1962) have discussed elsewhere, and as research in the area can be expected to elucidate in the future.

Soil processes

Soils of wild river forest lands perform important functions in the hydrologic and nutrient cycles. Water is absorbed and stored in soil, from which the vegetation draws vast quantities and transpires them during the growing season. The relatively small portion of the annual rainfall that is not used by vegetation percolates to the water table, and moves to bogs, lakes, and rivers (Hole, 1974). Some small brooks flow for considerable distances almost out of sight below a mat of roots of hemlock, cedar and other hydrophilic plants. With the spring melting of snow and frozen surface soil on uplands, before deciduous trees have leafed out, some water moves laterally (down-slope) through the upper soil horizons over the fragipan.

Except where rivers form cutbanks (which are comparatively rare in the Basin), the soils are shielded by vegetation from running water and they serve to filter out sediment, even much fine colloidal material. On the other hand, the aqueous extracts of the living plants, decaying wood and soil organic matter in the forest do contribute dark humic material to the wild rivers, giving them their characteristic yellowish brown tint. Black and Christman (1963) found that waters colored by organic materials from wilderness lands are surprisingly uniform over the continent and typically contain fulvic acids (about 90% of the organic fraction) and hymatomelanic and humic acids, ranging in all from 10 to 120 grams per liter with seasonal variability. These materials occur as negatively charged colloidal particles, as well as dissolved substances (Birge and Juday, 1934). Iron (0.1 to 2.0 ppm in water) is commonly associated with the organic matter. These data are not from the Pine–

Popple Rivers Basin but probably represent conditions in the lakes and streams there. The humus in wild rivers stimulates the growth of algae somewhat, perhaps because it carries nutrient elements in exchangeable form.

Nutrient cycling involves: 1) both mineral and humus portions of the soil, in which is present a complete complement of elements needed by native plants; and 2) the above-ground forest vegetation. The first category has always been considered to include fallen logs, branches, needles, leaves, and fruiting bodies. These, along with residues of associated decomposers, make up the surficial organic horizons of the soil. However, the bulk of the forest consists of dead wood of the standing boles and large branches. This wood differs from that of fallen logs of the soil proper only in the higher proportion of relatively undecomposed material. It is difficult to categorize this bulky dead organic matter as waste, because it contributes so importantly to the forest community by giving both mechanical support and nutrients to the living portion. Mills (1972) observed during his canoe trip that "a barn overgrown by popple decays into oblivion." That oblivion includes tangible wild soil. A roadside picnic grounds built by the Depression era Civilian Conservation Corps near the Highway 139 bridge over the Popple River was by 1970 overgrown with popple, grass and briars. "We observed nature struggling to heal the scars inflicted by man."

OPPORTUNITIES FOR STUDIES OF WILD SOILS

"No other geographic region has such a variety of life forms and such an ability to manifest the effect of environmental factors as does the forest" (Wilde *et al.*, 1949). Our knowledge of interactions between soils and native plants is far from complete. Most effort in soil survey has gone into the characterization and mapping of soils for agricultural, silvicultural and engineering purposes. Priority has been given to the demands for food and fiber for people and domestic animals, and materials for their shelter; the demand for stable soil conditions for the support of roads, buildings and pipelines; and the demand for soil conditions suitable to absorb and filter water and, locally, liquid wastes. The soils that researchers have observed to a depth of four or five feet in cultivated fields (which occupy little of the area of the Pine–Popple Rivers Basin) are in an ecological sense "decapitated" soils. They have lost the root mass of the original forest and the humus and forest litter layers, as well as the standing, three-storied forest itself. They have been made more compact than they were, and very probably conserve water and nutrients less efficiently than they did before the impact of man's activities (Bidwell and Hole, 1965). Accelerated soil erosion has occurred on cultivated fields by water and wind, and on slopes above road-cuts, by slump during thaws in spring.

The unusual opportunities that the Pine–Popple Rivers Basin offer for the study of wild soils may be indicated by the following topics.

(1) *Relationships between individual species of plants and soils.* We know that well developed Spodosols (Podzols) commonly occur under hemlock trees *(Tsuga canadensis)*, (Milfred, *et al.*, 1967), but need to investigate less obvious influences of other plant species on soil genesis in natural forest ecosystems of the Basin.

(2) *Relationships between plant communities and soils.* We know that mixed hardwood-conifer forest litter supports more earthworm *(Lumbricus terrestris)* activity than do pure coniferous stands. This is part of the reason for the presence of an A1 horizon in the mixed forests and its absence in many coniferous stands. Many such synecological details of soil genesis need to be worked out in the Basin.

(3) *Relationships between individual species of animals and soils.* Birds bring to soils grit regurgitated from their crops and nutrients in the form of excreta. Soils under roosting sites of crows (*Corvus* sp.), for example, receive notable deposits of these two kinds of materials. The work of beavers (*Castor* sp.) in flooding low-lying soil bodies alter soil properties over considerable areas, and these changes await serious study. One could list many species of animals whose influence on soils has not been documented carefully.

(4) *The influence of human activity on soils.* Comparative soil studies are needed between fields, pastures, second growth forests, selectively cut forests, and undisturbed forests. Of particular interest would be: 1) differences from site to site in the water budget, which could be measured by recently developed physical methods (Bouma *et al.*, 1973), and 2) effects of different methods of harvesting forest products in areas adjacent to the Rivers (Boyle and Ek, 1972).

CONCLUSION

The wild soils of the Pine–Popple Rivers Basin function to support forests and thus to influence the natural temperature, chemistry and steady flow regimes characteristic of these wild rivers. A general soil survey has been made of the watershed, particularly in the Florence County portion, but detailed soil ecological work has scarcely begun. The opportunities for long-term research on wild soils are excellent in the Basin.

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THE NOVEL AS A VEHICLE TO TELL THE STORY OF THE MENOMINEE INDIANS

William Steuber
Madison

What is to be done about the American Indian? The question has never been successfully answered. It has been a puzzle ever since Columbus reached the Caribbean and thought he had found India. The American Indian was an annoying problem to the early pioneers, to the westward settlers, to the United States Army, to every president and Congress from George Washington through Richard Nixon. The Indian question has been particularly troublesome in recent years with the take-over at Alcatraz, at Wounded Knee, and with the occupation of the Bureau of Indian Affairs in our nation's capital.

Wisconsin still puzzles over the Indian much as our forefathers did before we became a state. Currently the Menominee are in the headlines. Two decades ago they were prosperous, second only to the oil-rich Oklahoma Indians. Under pressure from Congress, they voted to terminate their reservation and become free citizens, supporting their own county. Today they are poverty ridden, and have successfully pleaded to again become wards of the federal government. The processes are now underway to disestablish Menominee County and to reestablish the Menominee Indian Reservation.

There are no easy answers to Indian problems, either among the Indians themselves, or in the Congress of the United States, Wisconsin, or anywhere.

The American Indian is still a generous natural resource. We made fortunes from him, giving him beads and brandy for his beaver. We traded cheap promises for good land. We put his profile on our pennies and our nickels, but let him own very few of them.

We are not finished merchandising Indians. We are now capitalizing our guilt, our compassion, our social consciousness in a flood of belated attention with varying motives. Jane Fonda and Marlon Brando have been typically loud in Indian causes. One wonders how much of this is truly for the Indian, how much for their own publicity.

Or take so many of the present books that seem to speak for the Indian. The accounts seem so stylized. Find an old Indian. Take a tape recorder. Ply him with whiskey. Let him cry and sing his heart out. Then take your notes and your tapes, rewrite his story into the current pattern of popular guilt, twist his halting words into your ideology, into your sense of timing, into your telling phrase, your witticism, your creation of something intimate, something significant.

One becomes highly suspect of ghost-written accounts, as-told-to presentations, two-person authorships and their ability to bulge, perhaps rupture, the honest line between fiction and non-fiction. Such dubbed-in writing may appear to present solid and substantial fact which in reality may be highly manipulated and distorted by the views, motivations, aims and skills of the co-author. A strong compulsion to take such liberties may be based on present reader preference for non-fiction, and better sales, over true novels.

Nevertheless, the novel is a writing form of historic power and honesty. In the hands of a Charles Dickens, an Upton Sinclair, a John Steinbeck, its created characters become more alive than actual people. Social problems are shown in the glare of truth, and a great strength is born to help solve those problems.

The Menominee Indians today are a troubled minority people, protesting white dominance more intensely now than at any other time in history. In order to understand and appreciate the problems of the Menominee Indian today, one should know how he lived before the white people overwhelmed him. One should know his basic weaknesses in the presence of a different culture, his beliefs, his fears, how he handled his world when he alone walked it.

The Great Lakes Menominee, before the white man, were a small and prosperous tribe. They had wild rice, maple sugar, beaver, sturgeon, bear and deer, wild fowl and passenger pigeon, in such plenty that food was no problem. They had abundant time to contemplate the mysteries, to instruct their young in countless legends and traditions, and to perform the endless rituals that would please the spirits.

All Indians were dominated by spirits. Every rock, tree, bush, wind, animal, stream, lake, storm or fire was a spirit. Christian missionaries, recognizing no such spirits, seemed to the Indian to be hopelessly insensitive. Only when God was described as the Great Spirit, could spiritual communication begin.

In the dream fast, a young person would go alone for three or four days without food, water, or shelter until in his parched delirium a spirit would come to be guardian and confessor to him for the rest of life. Elation and sense of great power came.

No Indian tribe north of Mexico had any kind of fermented or distilled liquor. When they were first treated to it by the white man, they felt the same elation, the same power, the same communion with all their spirits as their dream fast had given them. They quickly looked upon liquor as something good, something holy. With this extra appeal, in addition to the pleasure to the palate and the warming glow, Indians readily became alcoholic.

Indians before the white man came had no cows, goats, or sheep. Yet every child had milk for the first three years of his life. He nursed many months after he had learned to run and talk, but once he was weaned he never tasted milk again in all his life. Milk was for babies and only for babies. When the settlers came and brought their cows, and the Indians saw grown children and white adults drink milk they were horror stricken. To them it was a filthy abomination, a perversion of the worst kind. They turned their heads in utter disbelief and disgust.

White traders took Indian wives. They were a great help to the trader in getting him accepted among the tribes. It was a great honor for an Indian woman to be so chosen, and some became so proudly arrogant nobody could stand them.

But when the settlers came, as desperately as they needed women, no settler would ever take an Indian wife because they were no help at all.

They could not fry an egg.
They could not set a table.
They could not make a bed.
They could not milk a cow.

All primitive people become highly agitated by thunder and lightning. Thunder quickly becomes a part of their mythology. This was as true for the ancient Greeks and early Norsemen as for the American Indian, whose thunderbird is traditional with every tribe.

Even today, with all our modern sophistication, we too pay homage to thunder and its company. We pay high premiums for wind and hail insurance. Public utility companies and cities install lightning protection and keep emergency crews on standby during storms. We all keep our radios on during a tornado watch. There still are many farm families who get everybody up in the middle of the night to sit out a storm.

Try to imagine then, the fear that thunder and lightning could bring to an uninformed but imaginative Indian, crouching under bark slabs that leaked, that blew off with the wind, under an angry heaven striking at him with all the fury of the universe. His fear of lightning and thunder so overwhelmed him that he could find peace only through the mystic power of his medicine man. Only when the medicine man stripped naked and ran chanting all around the camp were the thunderers appeased and the camp made safe again.

Over and over again, Indian spokesmen tell us that Indians are not interested in the white-man's ambitions, or white economics, or white life styles, nor even white definitions of freedom or equality. The red man tells us that he does not want to imitate any other race, or be like any other people. He says he wants only to be an Indian and to be left alone so that he can be an Indian. Certainly one must accept that as a noble and a simple request. To be a brother to the deer and the bear, to be in accord with every tree and babbling brook, to walk as a natural creature of the woodland, to live in intimacy with all the spirits of the rocks and rains and winds, to live only with what Mother Nature sets before one, surely this is the ideal life.

This dream to go back fascinates, and is symbolic to young idealists, to the human-rights people, the ecologists, the nature scientists. It certainly must appeal to every thoughtful citizen who holds dear his own freedom.

All the natural riches of wholly Indian North America—vast beds of wild rice, maple groves bleeding rich sap, streams alive with sturgeon and beaver, the great plains black with buffalo, the woodland skies darkened with wild fowl, berries from spring to fall in every marsh and upland, grapes and nuts beyond all gathering. With all this boundless treasure, Nature working alone took more than three square miles of land to support each Indian.

If the Indians today could live primitively by themselves, it would be the highest priced living the earth has ever known. We would have to remove 197 million other Americans. We would have to take down our cities, bulldoze our highways back into the soil, abandon our farms, and return everything to the native prairies, marshes, and forests. Only then could an Indian live his ideal life as an Indian.

This is the dilemma the Indian creates for himself and for us. This is why the Indian himself makes it so difficult to help him. This is why, after four hundred years of trying we still cannot answer the Indian question either to his satisfaction or to ours.

Nature can renew, nature can replenish, nature can go on no matter how violently she has been insulted, but nature cannot go backward. Only in fiction, only in make-believe, can we go back to relive the days that once were.

GO AWAY THUNDER, a novel published in 1972, is a tale of the Menominee Indians many generations before Columbus. It is wholly sympathetic to the Indian viewpoint. As fiction, it can go back, it can re-live the times when the Menominee were the giants of the Great Lakes woodland.

Through nearly three hundred years of the fur trade, the woodland Menominee homeland on the north and west shores of Lake Michigan remained undisturbed, its culture intact. Once the European demand for beaver hats declined there was no economic reason whatsoever for a white man to stay in Menominee country.

Nothing much was asked of the Menominee until lumbermen took notice of the finest stand of white pine the world has ever seen on their ancestral lands. American enterprise, needing lumber and lots of it for expanding America, easily negotiated treaties to take the Menominee land. By that time we had already passed the middle of the 19th century, our nation was approaching the astonishing age of one hundred years, and we were affluent enough to have money to put into carefully detailed studies of the people who were here before we were.

The Bureau of American Ethnology as a part of the Smithsonian Institution began a series of cultural studies of Indian tribes, a series of studies continuing for many decades. The remarkable Menominee, essentially living the same as their ancestors long before the first white man in America, were studied and documented, their chiefs and medicine men explaining their traditions and values.

From these detailed ethnic studies, from the much earlier explorers' and traders' notes, from the early missionary documents it is possible to piece together a story of Menominee life when Indians alone occupied the northern woodland. With this authentic documentation, GO AWAY THUNDER was written. It recreates one year of early Menominee tribal life in the long long parade of mankind. The title, GO AWAY THUNDER expresses an awe, a fear, a plea to the unknown, a prayer to the mysteries by the primitive American Indian. GO AWAY THUNDER is also a symbolic cry toward the coming of the white man, the most awesome thunder of all.

This has been my work to find out about earlier Indians for a better understanding of the Indian of today. I have now completed, as a following novel entitled BEAVER, BRANDY, BEADS AND BELLS, the amazing story of their first contact with white civilization.

Later, after much more research, I intend to put into a third Menominee novel the continuing conflict between these proud Indians and white culture today.

LAKE WINGRA, 1837–1973: A CASE HISTORY OF HUMAN IMPACT[1]

Paul C. Baumann, James F. Kitchell,
John J. Magnuson and Terrence B. Kayes
University Wisconsin—Madison

ABSTRACT

Lake Wingra is a shallow, eutrophic lake bordered on one side by the City of Madison and on the other by the University of Wisconsin Arboretum. This paper recounts the history of the biological and hydrographic changes which occurred in the lake between 1837 and 1973. In the early 1900's, the area, depth and drainage patterns of the lake and adjoining wetlands were extensively altered by the activities of man. Early management practices (e.g. introduction of carp in the late 1800's, fish rescue and stocking operations during the 1930's and carp removal programs during the 1930's, 1940's and 1950's) had marked and often unexpected effects. The lake once had extensive bordering marshes, diverse aquatic macrophyte communities, and large northern pike and yellow perch populations. It now has few connecting marshes, dense stands of Eurasian water milfoil and is dominated by stunted bluegill and yellow bass. The number of macroinvertebrate species has been reduced; many larger forms have been eliminated. Since 1969, Lake Wingra and its watershed have been a major study site of the International Biological Program. Hopefully, ecosystem concepts derived from this project and the lessons of history will facilitate more ecologically sound management decisions.

INTRODUCTION

During the 1960's, the effects of cultural eutrophication on fresh waters became increasingly apparent to scientists and the general public (Hasler, 1973). Other planned and accidental disturbances by man have proven highly important in producing major changes in aquatic ecosystems. Among these, physical changes produced by dredging, draining and damming, introduction of non-native species, and activities associated with intensive recreational use (e.g., rough fish removal, weed cutting, sport fishing) have significantly altered many aquatic systems. All have occurred at Lake Wingra.

[1] Contribution No. 141, US–IBP, Eastern Deciduous Forest Biome and journal paper No. 86, University Wisconsin Arboretum.

Lake Wingra, Dane County, Wisconsin, is a shallow, hard-water lake with a surface area of 140 hectares and a maximum depth of 6.4 meters (Poff and Threinen, 1962). A dense littoral macrophyte community almost completely dominated by one species, *Myriophyllum spicatum* (Nichols and Mori, 1971), classifies the lake as highly eutrophic according to the scale of Swindale and Curtis (1957). "Whole-basin" mixing probably provides sufficient nutrients to support a rich algal flora throughout the growing season. Fish and invertebrate populations are also dense. Recreational use of the lake is intensive.

The lake has been the site of substantial scientific investigation because it is near the University of Wisconsin and its Arboretum. A chronology of investigations prior to 1968 concerning Lake Wingra is as follows: Birge (1891), Juday (1914), Cahn (1915), Pearse (1916, 1918), Pearse and Achtenberg (1918), Pearse (1921), Domogalla and Fred (1926), Wright (1928), Tressler (1930), Tressler and Domogalla (1931), Leopold (1937), Juday (1938), Frey (1940), Noland (1951), Threinen and Helm (1954), Neess, Helm, and Threinen (1957), Helm (1958, 1964), and Sachse (1965). Unpublished data and a variety of maps are in the files of the University of Wisconsin Arboretum Committee and the University of Wisconsin Archives. Noland (1951) summarizes much of the earlier records of the Wisconsin Department of Natural Resources (unpublished data in Water File).

The Lake Wingra basin is now under intensive investigation as an Eastern Deciduous Forest Biome site of the International Biological Program (IBP) (Adams et al., 1972). This project did not officially start until July 1, 1970, but preliminary investigations began in 1968. As part of the Analysis of Ecosystems Project, studies are being conducted to "secure an understanding of our emerging man-dominant ecosystems" and for "development of mathematical models and simulation of complex events in the ecosystem over extended periods of time." One major reason for this site's selection is that the "Lake Wingra watershed is representative of the situation existing in many watersheds throughout the eastern United States for it is markedly influenced by the activities of man." The site "offers an opportunity to assess relative importance of city versus natural areas," being bordered to the north by the city of Madison and to the south by the University of Wisconsin Arboretum (Anonymous, 1969).

The purpose of our paper is to collect, in one narrative, the diverse information available on Lake Wingra. We briefly describe the white man's settlement of the watershed, depict the hydrographic and biological history of the lake, and qualitatively evaluate changes related to human impact.

SETTLEMENT

Lake Wingra and the extensive marshlands surrounding it were used by the Winnebago Indians as a major hunting and fishing ground as late as 1925. "Winnebago tradition had it that the swamp would take over entirely when the last red man left the shores" (Sachse, 1965).

In 1837 Moses Strong came to the Madison area to make surveys for establishment of the new state capitol. At that time some 500 to 1,000 Winnebago Indians were camped around Lake Wingra. The Winnebago liked to camp by the lake because of the "great abundance of fish in its waters and game on its shores" (Brown, 1915). After the financial crash of 1857, Levi B. Vilas, owner of an enormous tract north and south of Lake Wingra, sold several parcels of land. In 1865 Frank M. Grady settled a tract southwest of the lake, and "by the seventies a few isolated homesteads dotted the north shore" (Sachse, 1965).

During these early years, Dead Lake (later the Winnebago name, Wingra [Duck], was adopted) was relatively inaccessible. In 1841 only Indian trails penetrated to the lake, and an old territorial road (now Fish Hatchery Road) skirted the southeastern marshland. In her "Map of Lake Wingra before 1915," Sachse shows many of Madison's major streets in approximately their present-day locations, and shows trails following the north and south margins of the marshland.

Aside from agricultural activities, major physical alterations of the watershed did not begin until 1905, when dredge and fill operations began in the construction of Vilas Park. Between 1911 and 1920 the Lake Forest Land Company made its abortive attempt to build a "model suburb" in the southern lowlands. Urbanization of the north shore followed the sporadic development of Nakoma and westward expansion of Madison, beginning about 1910 (Sachse, 1965).

Throughout the early years, Wingra's rich populations of muskrat, waterfowl, game fish and turtles were heavily exploited. Since then the lake, its biota and surrounding marshland have been dramatically altered by the influence of man. In his 1934 reminiscences of the 1870's, L. B. Rowley stated the point simply: ". . . it isn't the same lake at all" (Sachse, 1965).

HYDROGRAPHY

From earlier scientific papers, unpublished theses, public records, maps and accounts of private citizens, Noland (1951) collected detailed information about the hydrographic history of the Wingra basin. His accounts did not, however, reconstruct a picture of the basin's original nature.

The Original (ca. 1900) Shoreline and Wetlands

Reconstruction of Wingra's original hydrography is difficult because scientific investigations were not done before the period of maximum hydrographic change, and early accounts are conflicting and unclear. The lake's surface has been reported to be 217 hectares (Pearse and Achtenberg, 1918), 81.0 hectares (Juday, 1938), 133 hectares (Noland, 1951), and 140 hectares (Poff and Threinen, 1962). An example of semantic confusion is the frequent but undefined use of the word "marsh." This term describes a variety of conditions. To avoid further confusion, we use the fresh-water classifications described by Smith (1966).

Our attempt to reconstruct the original shoreline and surrounding marshland is a stepwise alteration of present-day maps accounting for known and inferred hydrographic changes in the past.

Figure 1 indicates present shorelines, local geographic references, and other physical characteristics of the area adjacent to the lake. The lake is 262.9 m above sea level, 1 m higher than Lake Monona (United States Geological Survey, 1959). According to Nichols and Mori (1971), the present spillway dam (Fig. 1) maintains a 0.6 m head between lake level and Murphy's Creek. The creek falls the remaining distance to Lake Monona. The dam and McCaffrey Drive isolate Gardner Marsh from the lake proper. The channels in this wetland measure 0.3 to 0.6 m below lake level (our observation) and drain into the creek above Fish Hatchery Road. Except at the outlet, a strip of high ground separates marsh from creek (Fig. 1). The northwestern two-thirds of the wetland is primarily a mixture of shallow and deep fresh marsh. The southeastern third is dominated by shrub swamp, which becomes increasingly dry toward the outer margins. The ponds and channels in Gardner Marsh are open freshwater areas, although vegetation is dense in some parts. Both Redwing Marsh and the marsh west of Edgewood Bay (Fig. 1) are deep fresh marsh, but become rapidly shallow shoreward. The western wetland, including Wingra Marsh and Wingra Fen (Fig. 1), is a patchwork of fresh meadow and shrub swamp. Shallow fresh marsh borders the lake's southwestern shore and merges with a narrow bank of deep fresh marsh toward open water. The lake's water originates from surface runoff, springs and, along the urbanized shore, storm sewers and drain pipes (Noland, 1951). Spring water enters the lake directly and via Ho-nee-um Pond and Gorham, Nakoma, Big Spring, East Spring and Marshland creeks (Fig. 1).

Early accounts (Birge, 1891; Cahn, 1915; Juday, 1914; Rowley, 1934 in Sachse, 1965) agree that the entire shoreline was marshy and marsh areas were more extensive. They also suggest that the

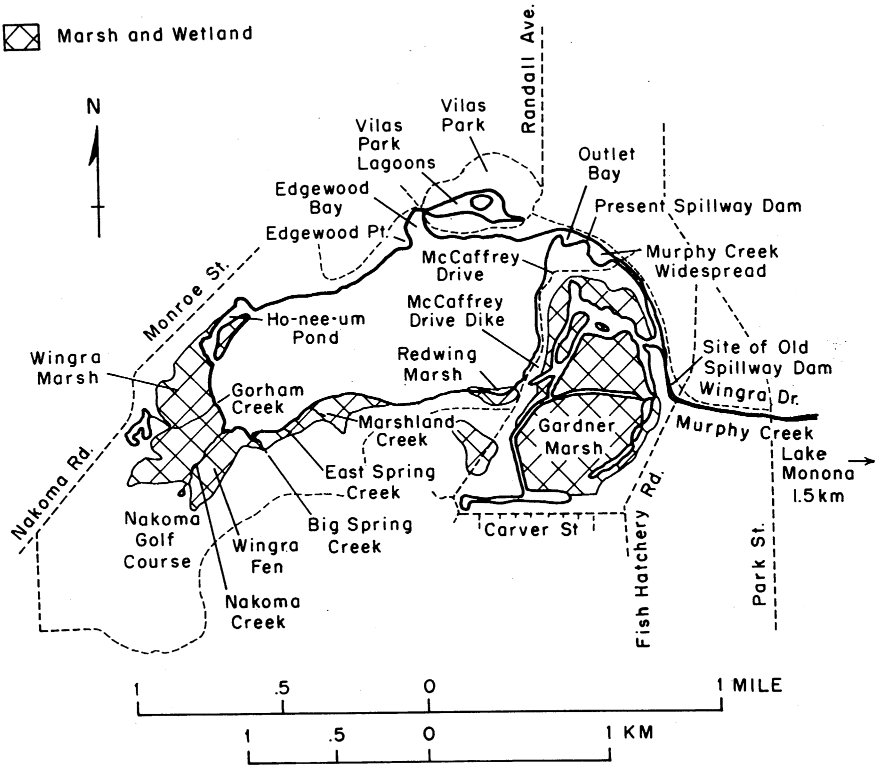

FIGURE 1. Lake Wingra, adjacent wetlands, and major streets (----) in early 1970's. Combined from field observations and maps by the U.S. Geological Survey (1958) and the University of Wisconsin Arboretum Committee (no date).

lake had a greater area. Data collected by Noland (1951) provide two reasonable explanations. Early water levels were higher, about 1.3 m above Lake Monona or about 0.3 m above the present level. The outlet was located just above the bridge at Fish Hatchery Road (Fig. 1), and upper Murphy Creek and much of Gardner Marsh were probably part of the original lake.

A hypothetical shoreline (Fig. 2A), taking account of the above information, was made by designating a point above Fish Hatchery Road as the original outlet and by drawing a line midway between the lake's present shoreline at 262.9 m and the 263.4 m contour line determined from a U.S. Geological Survey Map (1959). Earth-moving operations were assumed not to have appreciably altered the contours.

Additional information substantiates the proposed shoreline in Fig. 2B. Both Rowley (Sachse, 1965) and a map made by Moritz

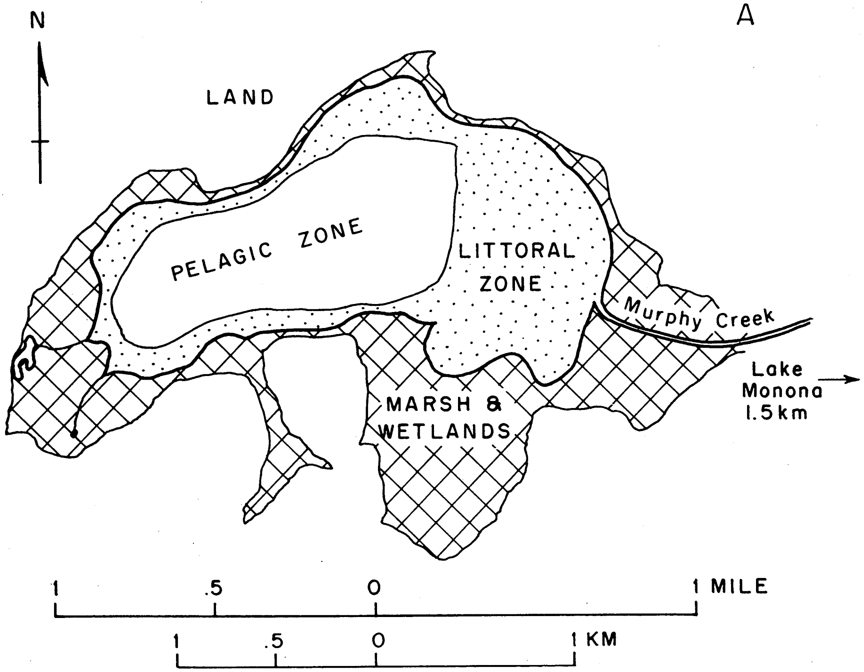

FIGURE 2A. Pre-1900 reconstruction of Lake Wingra, its wetlands and littoral zone. Scaled to map by U.S. Geological Survey (1959).

in 1904 (this map is currently in Wisconsin Historical Society Archives) indicate that Gardner Marsh originally extended to what is now Fish Hatchery Road. The road probably marks the outer boundary of the original lake's emerging vegetation. Higher water must have covered the southern end of the strip now separating Gardner Marsh from Murphy Creek. Because land-fill operations created the peninsula at Vilas Park (Juday, 1914; Noland, 1951), the original shoreline must have been continuous from Murphy Creek along the northern edge of the present Vilas Park Lagoons (Figs. 1 and 2A). The higher water probably covered much of Edgewood Point. An incomplete survey done in 1834 (Wilcox, 1936) confirms the proposed shoreline of the eastern half of the lake. Two spillway dams maintain a 0.3 m head between Ho-nee-um Pond (Fig. 1) and the lake (Sachse, 1965). A soils map by Retzer (1950) suggested that the island separating pond from lake was formed by dredge spoils, so the hypothetical shoreline was placed along the western edge of the pond.

The area deeper than 2.0 m on the present contour map (Fig. 3) likely represents the original pelagic zone of the lake and is indicated as such in Fig. 2A. Maximum depth was probably about 4.3

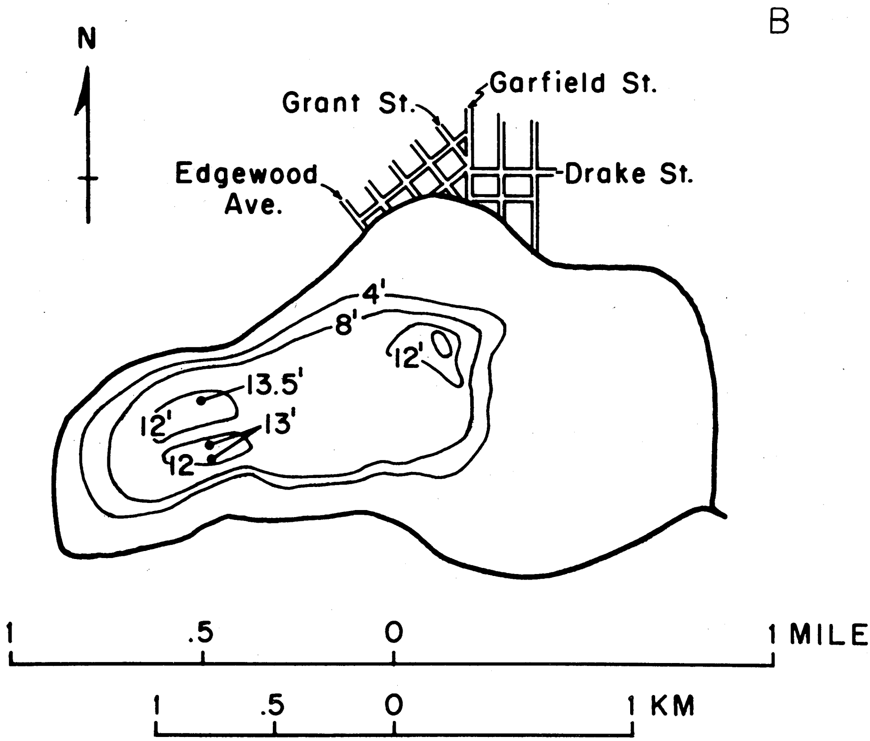

FIGURE 2B. An early (1904) map of Lake Wingra redrawn from an original by Moritz. Depth contours are given in feet. Streets identified are those with same names today.

m in the area midway between what is now Edgewood Bay and the southern shore (Fig. 2B). The remainder of the basin was largely a gradual and regular slope to all shorelines north and south with extensive shallow littoral zones to the east and west.

The wetland originally surrounding Lake Wingra "covered a wide area in all directions except the adjoining high land on the north side and a wooded knoll on the southwest about twenty acres in extent" (Rowley (1934) in Sachse, 1965). Water from springs in and around the margin of the wetland drained into the lake. In the northeast, the marshland's outer edge was probably defined by Reynolds Spring, which was situated "just south of the old Dividing Ridge" (Noland, 1951) and had a creek as its outlet. In the west and southwest the wetland extended "to Monroe Street and Nakoma Road" and took "in the flat part of what is now the Nakoma Golf Grounds" (Fig. 1) (Rowley (1934) in Sachse, 1965).

Apparently the original wetland extended almost up to the 266.6 m contour line (Fig. 2A). The "Map of Lake Wingra Before 1915"

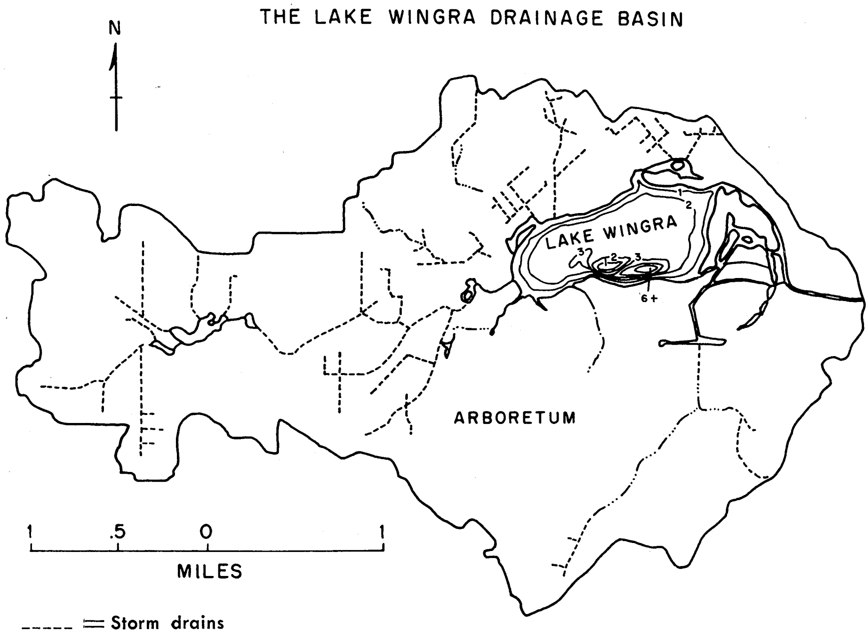

FIGURE 3. Recent Lake Wingra drainage basin and storm sewer system including approximate depth contours of the lake at 1 m intervals.

(Sachse, 1965) verified the proposed outer margin. The area from this wetland margin to proposed shoreline was likely a mixture of fresh meadow and shrub swamp. Cahn (1915) reported that the western wetland was covered with up to 30 cm of water in May and was muddy through summer and autumn.

Moritz, a geologist, surveyed the lake and site of Vilas Park prior to construction. His map (1904) indicates that the original northeastern shoreline roughly corresponded with what is now Vilas Park Drive (Fig. 1) and that the eastern region of the lake was a broad, shallow area extending to Fish Hatchery Road. We located Moritz's map after having reconstructed the lake based on contour lines for Fig. 2A. In general, the margins of the littoral zone area proposed in our reconstruction are confirmed by Moritz's map suggesting that the area of the lake was approximately 265 hectares. The current area of the lake is 137 ha. (see Huff et al., 1973, for a detailed summary of present physical characteristics). Thus, prior to major construction activity, the area of Lake Wingra was approximately 1.9 times greater. Including the surrounding marsh and wetlands, the area was about 3 times greater than that at present.

Major Changes to Shoreline and Wetlands

The assumption made in Fig. 2A, that the 263.4 m contour line has not changed appreciably, is probably correct. But some changes have occurred and are documented below, primarily from Noland (1951). The east and southeast end of the original lake and wetland was most altered. This area now includes the lowland east of Murphy Creek, the full length of the creek, Gardner Marsh, the sections east of the marsh to Park Street and south beyond Carver Street as well as the south and east sides of the lake proper (Figs. 1 and 2A).

In 1905 and 1906 (Fig. 1, present streets as landmarks), a channel was dredged from the bridge of Fish Hatchery Road in an arc along Wingra Drive to a point south of Randall Avenue. A wooden lock and spillway dam were erected below the bridge to maintain the lake at its original level. In 1907 and 1908 the creek's entire length below the bridge to Lake Monona was dredged. Though documentation was not found, spoils from these operations were probably used to fill adjacent wetlands.

Between 1914 and 1920 the Lake Forest Land Company attempted to build a "model suburb" in the southern wetland beyond the 263.4 m contour line. At this time, a dike (McCaffrey Drive dike) must have been built from the south shore and southeast to the outlet to isolate the present Gardner Marsh from Murphy Creek and the lake proper (Fig. 1). Channels, dug in the marsh and wetland to the south, emptied into the creek below the old spillway dam. This lowered the water level of the marsh below the lake level and diverted water from four southern springs away from the lake. In 1917 the dike was breached at the southeast corner of the lake, effecting a 1.0 m fall in the lake's level and a dramatic reduction of surface area. The present lock and spillway dam (Fig. 1) were built and the dike was closed in 1919. The lake filled to its current level about 1.0 m above that of Lake Monona. Murphy Creek was then dredged to levels approaching Lake Monona's to further facilitate drainage of marsh and wetland.

Beginning in 1915, a dredge working 12 hours a day, spring through fall (Sachse, 1965), removed bottom materials from the lake near its south shore. By autumn of 1916, a trench 9.3 m deep had been dug. This has partly filled to the present depth of 6.4 m (Fig. 3) which is currently the maximum depth in the lake (Poff and Threinen, 1962). The areas above and below the present dam were dredged, producing Outlet Bay and Murphy Creek Widespread. Spoils may have been used to close and strengthen McCaffrey Drive dike.

In spite of all the above effort, little solid land was produced. The Lake Forest Land Company was bankrupt in 1922.

Development of the University of Wisconsin Arboretum and urbanization have affected the east and southeast end of the original basin. A soils map by Retzer (1950) indicated extensive filling east of Gardner Marsh between Fish Hatchery Road and Park Street (Fig. 1). Construction of Wingra Drive and McCaffrey Drive raised shores along their routes. In 1936, channels in Gardner Marsh were redredged (Sachse, 1965), but since then, sedimentation has partly filled them.

The northeast end of the original basin was greatly altered by the construction of Vilas Park in 1905, 1906 and 1913 (Noland, 1951). The area now in the outer part of Edgewood Bay (Fig. 1) was dredged to over 4.0 m. Marsh and wetland north of the present Vilas Park Lagoons were filled and the shore raised. Fill was also used to construct the peninsular part of the Park. Vilas Park Lagoons were dredged to 1.6 m in the center. They were redredged in 1941, and the sediments deposited on an island in the center. Removal of groundwater by new wells combined with dredging and filling destroyed five springs in the original marsh. The depth in Edgewood Bay rapidly decreased as materials eroded from shore. The outer part of the bay is now about 1.2 m (Fig. 1).

The west end of the original basin was altered when Ho-nee-um Pond was built in 1938 and 1939 (Fig. 1). Material dredged from the pond site was used to form an island between pond and lake. Spillway dams were constructed at each end of the island, and the pond's water level was established 0.3 m above the lake. Dredged material was also deposited west of the pond and along the lake's shore north of the pond (Sachse, 1965).

Along the north shore, 16 springs have ceased to flow. This probably resulted from reduced replenishment of ground water owing to the construction of buildings, streets and storm sewers. Runoff from the northern and western regions of the drainage basin now reaches the lake primarily by the storm sewers (Fig. 3).

Current land use patterns have been summarized by Cullen and Huff (1972). Excluding the lake proper, more than 20% of the watershed has been altered to the extent that it is impervious to water. Buildings occupy 6.3%; roads, 8.6%; drives, 2.3%; parking lots, 1.5%; and sidewalks, 1.0%. Natural forests, primarily in the University Arboretum, comprise 16.0%, while lawns, parks, cemeteries and golf courses make up the remaining 63.6%. Although the latter are collectively termed "natural" land areas, they reflect the impact of human use. Selection for fast growing grasses, ornamentals and trees has resulted in a 30% greater productivity in comparison to equal-aged forests within the Arboretum (Lawson, Cottam and Loucks, 1972). Further, landscaping of lawns, parks and gardens and applications of fertilizers ultimately increase the nutrient load of runoff waters entering storm sewer systems (Huddleston, 1972).

Summary

In about 1900 Lake Wingra had a shallower maximum depth and covered about twice the area that it now does. Surrounding marsh was more extensive which, in combination with the original lake, provided a wetland and lake area nearly three times greater than that at present. These changes have been directly caused by dredging, draining and construction of dams and dikes. Other hydrographic effects of man on the lake were induced by alterations of soils, vegetation, ground water sources and surface water runoff patterns.

AQUATIC MACROPHYTES

The Original Vegetation

Wetlands of various types surrounded Lake Wingra in the late 1800's. Tamaracks were abundant around the southern shore until 1870. The soil of the East Marsh is composed of peat, from which tamarack branches, logs, and cones have been recovered. Although no good descriptive accounts from this early period exist, the assumption can be made that the bog flora usually associated with tamaracks was probably also present (Irwin, 1973).

Broad margins of marsh still surrounded Lake Wingra around 1900. Horsetails *(Equisetum)*, sedges *(Carex)* and wild rice *(Zizania aquatica)* were probably included in the wide margin of "weeds" described by Rowley (Sachse, 1965) along with cattails *(Typha latifolia* and *T. angustifolia)* and a bulrush *(Scirpus validus)*, which are now the dominant emergent forms (Nichols and Mori, 1971). Dense growths of *Chara* were interspersed between areas of wild rice and reeds (Birge, 1891). Wild celery *(Vallisneria americana)* was particularly abundant and received special note in Rowley's accounts (Sachse, 1965). Almost the entire lake bottom was covered with water plants of various kinds (Birge, 1891). Accounts after 1900 agree that the lake's entire shoreline was "marshy," that submerged macrophyte beds were extensive, and that wild rice was profuse (Cahn, 1915; Juday, 1915; Leopold, 1937; and Rowley (1934) in Sachse, 1965).

Other native Wisconsin species currently found in Lake Wingra that were likely present when the first white settlers arrived include four species of small floating plants *(Lemna minor, L. trisulca, Spirodela polyrhiza* and *Wolffia columbiana)*, two species of water lilies *(Nuphar variegatum* and *Nymphaea tuberosa)* and a group of submerged macrophytes including: *Potamogeton pectinatus, P. nodosus, P. richardsonii, P. zosteriformis, P. foliosus, P.*

natans, Zanichellia palustris, Najas flexilis, Anacharis canadensis, Heteranthera dubia, Ceratophyllum demersum, Utricularia vulgaris and *Ranunculus longirostris* (Nichols and Mori, 1971).

Type, abundance and distribution of aquatic macrophytes have changed dramatically over the past century. Many aspects of these changes can be attributed to man.

Major Changes in the Vegetation

In the southeast regions of the original lake, changes in littoral vegetation were related to dredging and filling. The net result was the transformation of a wide littoral area, probably rich with wild celery, coontail *(Ceratophyllum demersum)*, pondweeds *(Potamogeton spp.)*, water lilies, wild rice, bulrushes, cattails and sedges into Gardner Marsh, which is dominated by cattails. Channels in this marsh and Murphy Creek now contain dense growths of Eurasian water milfoil *(Myriophyllum spicatum)*, though water lilies are still common.

In the northeast, construction of Vilas Park by dredging and filling reduced the broad margin of weeds and cattails described by Rowley (Sachse, 1965). A sand beach was built on the peninsula and is still maintained. Mechanical harvesting and chemical treatment are used to prevent growth of aquatic plants around Vilas Park and the outlet to Murphy Creek (Nichols and Mori, 1971).

Considering the entire lake, changes in water level had particularly disturbing effects on aquatic vegetation. In 1917 the level was dropped 1.0 m; in 1919 it was raised 0.7 m to its present height, 1.0 m above Lake Monona. Fluctuation of water level and overwinter drawdowns are commonly used to inhibit growth of aquatic plants (Black, 1968; Beard, 1969). The net reduction of water level by 0.3 m also substantially reduced the lake's littoral zone.

In addition to hydrographic changes, introduction of exotic species altered the vegetation in the lake. The carp *(Cyprinus carpio)* was introduced into waters connected to Lake Wingra in the late 1800's, was common by 1915, and was a dominant by 1930 (see FISHES of this paper). Carp destroy vegetation directly by uprooting plants, and indirectly by increasing turbidity and siltation (Cahn, 1929; Cole, 1904; Cahoon, 1953; Black, 1946; and Threinen and Helm, 1954). Carp have an especially deleterious effect on wild celery and wild rice (Cole, 1904). Records of the Wisconsin Department of Natural Resources (unpublished data in the Water File) indicate that Lake Wingra was nearly denuded of aquatic macrophytes during the period of carp dominance from the late 1920's through 1955. From 1936 through 1955, an intermittent carp removal program was conducted by the Wisconsin

Conservation Department with the cooperation of the University of Wisconsin (reviewed by Helm, 1958, and more fully described in FISHES of this paper). By 1956, biomass and species diversity of aquatic plants, especially water milfoil, coontail and pondweeds had increased (Helm, 1958). Carp removal and subsequent macrophyte growth have not reduced turbidity because dense phytoplankton populations have characterized the lake since 1956 (Helm, 1958; Koonce, 1972).

Owing to hydrographic disturbances, introduction of exotics, or a combination of factors, several native species disappeared from Lake Wingra. Wild celery, *Potamogeton freisii, P. illinoinensis, P. amplifolius* and *P. praelongus* have not been collected later than 1929 (Nichols and Mori, 1971). The decline of wild rice has not been documented, but it is no longer present.

The Eurasian water milfoil now dominates the macroflora of all Madison lakes, including Lake Wingra. It was introduced to the Chesapeake Bay region of North America around 1900 and reported in Wisconsin by 1936 (Nichols and Mori, 1971). Although its appearance and increased abundance in Lake Wingra are not documented, Helm (personal communication) recalls that milfoil was not the dominant macrophyte in the late 1950's. Rather, pondweeds were most abundant after carp removal.

The Present

Gardner (or East) Marsh vegetation at present is composed of a variety of terrestrial and aquatic plants with shrubs invading the open areas and trees located along the edge. Seven major communities exist, including tree, shrub, wet meadow, aster-solidago, calamagrostis, cattail, and nettles. The large nettle community thrive on burnt peat soil, and was apparently established after the original marsh had been dried and destroyed by fire (Irwin, 1973).

Presently, five littoral communities occur in Lake Wingra as follows (Nichols and Mori, 1971): shallow water *Myriophyllum,* 68%; deep water *Myriophyllum,* 13%; *Potamogeton–Myriophyllum,* 17%; *Nuphar,* 5%; *Nymphaea,* 2%. Dominant emergents are *Typha latifolia, T. angustifolia* and *Scirpus validus.* The littoral zone extends to 2.7 $\pm$ 0.4 m, a depth primarily dictated by light penetration, and covers almost one-third of the lake's surface area. Since water milfoil *can* grow from depths greater than 4 m, a major reduction in turbidity might allow stands to develop throughout the lake. Native pondweeds and coontail are largely limited to depths less than 2 m.

The dense growths of littoral vegetation have considerable influence on the lake. They provide shelter from predation for many juvenile fishes, thereby increasing survival and population densities of panfish species in particular (Andrews and Hasler, 1942). Storm sewer waters are literally "filtered" by littoral vegetation. The lake is thus buffered from rainfall-induced pulses of allochthonous nutrients (MacCormick et al., 1972). Finally, dense macrophytes provide substrate, cover and food for many aquatic invertebrates which can ultimately be associated with distributional dynamics of fishes (Baumann and Kitchell, 1974).

In summary, many of the present physical and biological conditions of Lake Wingra are directly related to changes in the aquatic macrophyte component since the carp removal program.

PHYTOPLANKTON AND NUTRIENTS

The status of phytoplankton communities and nutrients are not available for Lake Wingra around 1900, but dominant forms listed for 1928 by Tressler (1930) generally correspond to present observations (Koonce, 1972). Thus, changes in the assemblages of phytoplankton do not appear to have accompanied the dramatic changes in the macrophyte associations. Differences in analytical methods prevent quantitative comparisons of phosphorus concentrations reported by Tressler and Domogalla (1931) with those determined by Koonce (1972) or Kluesner (1972). It appears, however, that phosphorus concentrations in open water have been reduced over recent time rather than increased. In addition, data summarized by Isirimah (1972) suggest that nitrogen concentrations have not markedly increased since 1928 (Table 1).

In spite of these negative data, the trophic status of Lake Wingra undoubtedly has been influenced by man's activities over the past century. The present storm sewer systems provide 80–90% of the total annual phosphorus loading in direct runoff to the lake (Kluesner, 1972) rather than through flow exposed to retention-by-soil processes. Allochthonous particulate carbon input (leaves, twigs, etc.) are similarly diverted from terrestrial decomposition. For example, more than 1 metric ton (dry weight) per year comes from the Manitou Way drainage, which represents less than 10% of the total storm sewer system (Gasith, et al., 1972; Gasith and Hasler, 1973). As mentioned before, vertical mixing in this shallow lake probably maintains sufficient nutrients in the water column to support high algal production throughout most of the growing season. With little or no direct supporting data to the contrary, we can only speculate that high productivity also characterized Lake Wingra prior to human perturbations of the drainage basin. The historic use of the area as a major hunting and fishing ground

TABLE 1. COMPARISON OF NITROGEN CONCENTRATIONS IN LAKE WINGRA BASED ON ISIRIMAH (1972, TABLE 1). DATA FOR 1928–29 ARE FROM TRESSLER AND DOMOGALLA (1931), FOR 1960 FROM CLESCERI (1961), AND FOR 1970 FROM KLUESNER (1972)

Year	Nitrogen Species	Average Concentration (mg N/liter) May	June	July	Aug.	Sept.
1928–29	NO_3-N	0.10	0.05	0.05	0.05	0.10
1960		0.10	0.20	0.10	0.10	0.10
1970		0.12	0.14	0.09	0.06	0.06
1928–29	NH_3-N	0.15	0.20	0.30	0.20	0.20
1960		0.10	0.10	0.30	0.20	0.70
1970		0.06	0.06	0.08	0.08	0.06
1928–29	Org-N	1.0	1.2	1.6	1.6	1.5
1960		1.5	1.5	1.5	1.5	1.5
1970		0.4	1.1	1.3	1.5	1.2

(Sachse, 1965) may lend some credence to this idea. Yet, the present algal productivity (Koonce, 1972) seems too high for an unmodified lake with a small forested watershed and, in 1928, when the first studies were done, the lake had already undergone tremendous man-induced alterations.

INVERTEBRATES

Prior to 1900, Birge (1891) provided a list of cladoceran zooplankton found in Lake Wingra that included 48 species (Table 2). This diverse fauna included a number of large open water species such as *Daphnia pulex* and *D. Schödleri.* Although substantial changes in the taxonomy of cladocera have been made since Birge's time, the list can be validly compared with the lake's present cladoceran fauna.

Data on benthic invertebrates are available only as early as 1929, when Tressler (1930) was active on the lake. The sub-littoral benthos was represented by a diverse assemblage of macroinvertebrates that included aquatic insects, water mites and mollusks. The littoral benthos was diverse also, but was dominated by the amphipod *Hyalella azteca* which constituted nearly 90% of the macro-invertebrates.

Dramatic changes have occurred in the communities of cladoceran zooplankton and in the benthic invertebrates.

Only 23, or one half, of the cladocerans present in 1891 are still present in lists (Table 2) prepared by Teraguchi (1970) and White and Hasler (1972). Those no longer present include several

TABLE 2. CLADOCERAN SPECIES RECORDED FROM LAKE WINGRA BY BIRGE (1891) AND MORE RECENT STUDIES (HASLER AND WHITE, 1971)

Species	Present		Species	Present	
	1891	1971		1891	1971
Acroperus harpae	X	X	*Dunhevia crassa*	X	X
Alona affinis	X	X	*Eurycercus lamellatus*	X	X
Alona costata	X		*Graptoleberis testudinaria*	X	
Alona guttata	X		*Holopedium gibberum*	X	
Alona quadrangularis	X	X	*Ilyocruptus sordidus*	X	
Alona rectangula	X		*Ilyocryptus spinifer*	X	X
Alonella excisa	X		*Latona setifera*	X	
Alonella exigua	X		*Latonopis occidentalis*	X	
Bosmina longirostris	X	X	*Lathonuria rectrirostris*	X	
Camptocercus macrurus	X	X	*Leptodora kindtii*	X	X
Camptocercus rectirostris	X	X	*Leydigia quadrangularis*	X	X
Ceriodaphnia laticaudata	X		*Macrothrix laticornis*	X	
Ceriodaphnia megalops	X	X	*Macrothrix rosea*	X	X
Ceriodaphnia pulchella	X		*Ophryoxus gracilis*	X	
Ceriodaphnia quadrangula		X	*Oxyurella tenuicaudis*	X	
Ceriodaphnia reticulata	X	X	*Pleuroxus denticulatus*	X	X
Chydorus globosus	X		*Pleuroxus procurvus*		X
Chydorus ovalis		X	*Pleuroxus striatus*	X	
Chydorus sphaericus	X	X	*Pleuroxus trigonellus*	X	
Daphnia ambigua		X	*Polyphemus pediculus*	X	
Daphnia galeata	X	X	*Sida crystallina*	X	X
Daphnia pulex	X		*Scapholeberis aurita*	X	
Daphnia retrocurva	X	X	*Scapholeberis kingi*	X	X
Daphnia schodleri	X		*Simocephalus serrulatus*	X	X
Diaphanosoma brachyurum	X	X	*Simocephalus vetulus*	X	
D. leuchtenbergianum	X	X			
Drepanothrix dentata	X		TOTAL	48	27

Daphnia spp. and *Ceriodaphnia* spp. that are relatively large organisms. Only 4 new species have been added to the list.

Intensive sampling in 1970–1972 of the benthos and the fauna on littoral macrophytes revealed an invertebrate fauna dominated by small chironomids. No live mollusks, no relatively large aquatic insects, and only two individuals of *Hyalella* were noted among the tens of thousands of invertebrates identified by Peterson and Hilsenhoff (1972). Perhaps more importantly, *Hyalella* rarely has been discovered in the hundreds of fish stomachs analyzed to date from 1970–1971 samples (Magnuson and Kitchell, 1971; Baumann and Kitchell, 1974), whereas they were common in fish stomachs from 1954–1956 (Helm, 1958).

Few data are available that allow us to determine the time course of the above changes during the last 80 years or to relate those changes to known causes. However, intense fish predation on larger invertebrates may well explain a rather recent decline of larger cladocerans and benthos in Lake Wingra. Dense panfish populations produced virtual or real extinctions of similar species from ponds through size-selective predation (Hall et al., 1970). *Hyalella* is still abundant in the littoral zones dominated by Eurasian water milfoil in neighboring Lakes Mendota and Monona and remains as a dominant food of many fishes (El Shamy, 1973; Brauer et al., 1972). Our experience suggests that panfish populations in the latter two lakes are not as dense as in Lake Wingra.

Intensive fish predation on aquatic invertebrates is the best documented but not necessarily the sole explanation for the decrease in diversity of cladocerans and functional extinction of *Hyalella* in Lake Wingra. We speculate that these dramatic changes occurred since the mid-1950's.

FISHES

The following represents a journey through time, from the Indian fishing grounds of the 1800's to the children's panfish lake of 1973. The fish community will be examined from early records (1837–1904), the period of major hydrographic change (1905–1925), a period of biological adjustment (1926–1936), a period of new species introductions (1937–1949), a period of major carp removals (1950–1957), and a second period of biological adjustment (1958–1973). When possible, explanations for changes in communities or populations will be attempted.

As a graphic summary of the dynamics, we estimated the timing of introductions and extinctions of major fish species (Fig. 4). In addition, we reconstructed their relative abundances on a similar time scale and related changes in abundance to major perturbations by man (Fig. 5). Information for these reconstructions was derived primarily from surveys by biologists from the University of Wisconsin—Madison and carp seinings by the Wisconsin Conservation Department.

Period of Early Records (1837–1904)

Fish were referred to as being plentiful in the early years. Our interpretation of the species list mentioned by Rowley (1934) is: longnose gar *(Lepososteus osseus)*, northern pike *(Esox lucius)*, black bass *(Micropterus salmoides)*, sunfish (*Lepomis* spp.), crappies (*Pomoxis* spp.) and "yellow bass," a local term at that time for the smallmouth bass *(Micropterus dolomieu)*. Pickerel were also mentioned, but the term seemed to be used interchangeably with northern pike. Earliest scientific investigations did not find any true pickerel *(Esox niger* or *E. americanus)*.

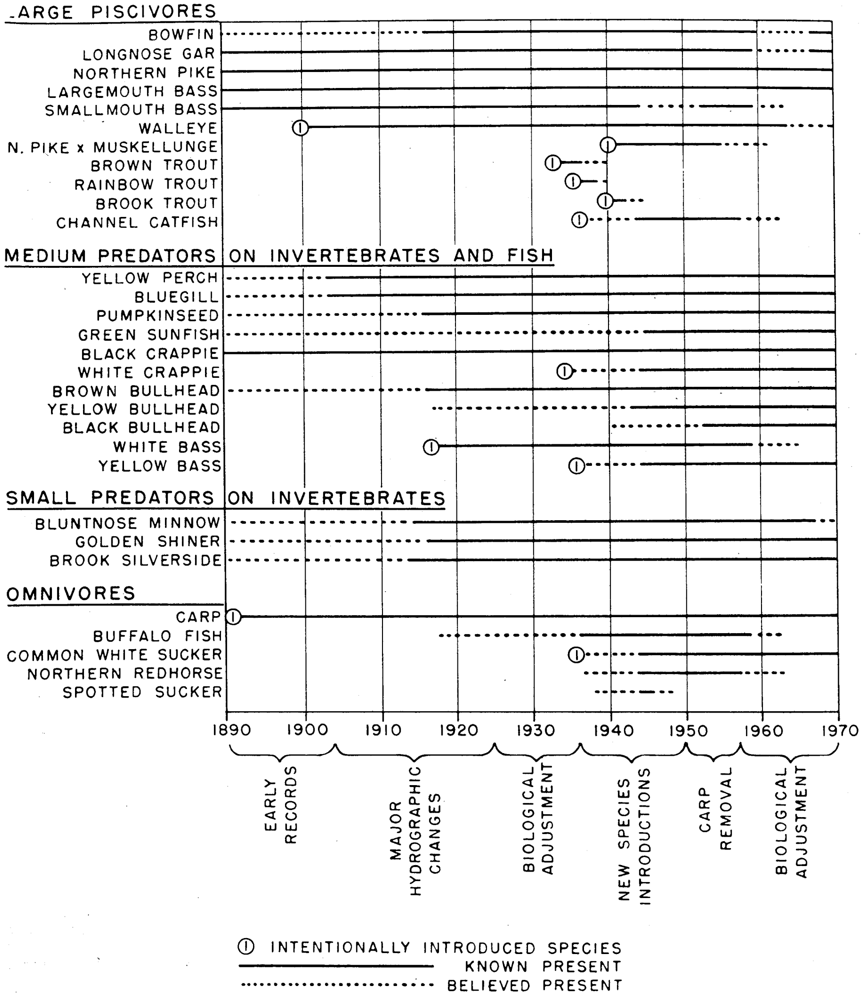

FIGURE 4. The fish community of Lake Wingra from 1890 to 1973, reconstructed from the literature showing presence and absence.

A biological study by Marshall and Gilbert (1905) in 1902–1903 mentioned four fishes from Lake Wingra: black crappie *(Pomoxis nigromaculatus)*, bluegill *(Lepomis macrochirus)*, largemouth bass *(Micropterus salmoides)*, and yellow perch *(Perca flavescens)*. Undoubtedly other species were native, but these conclude the documented list of fishes from early records (Fig. 4). Smaller panfish and forage species were seldom referred to individually by name. These species will be discussed in the next section.

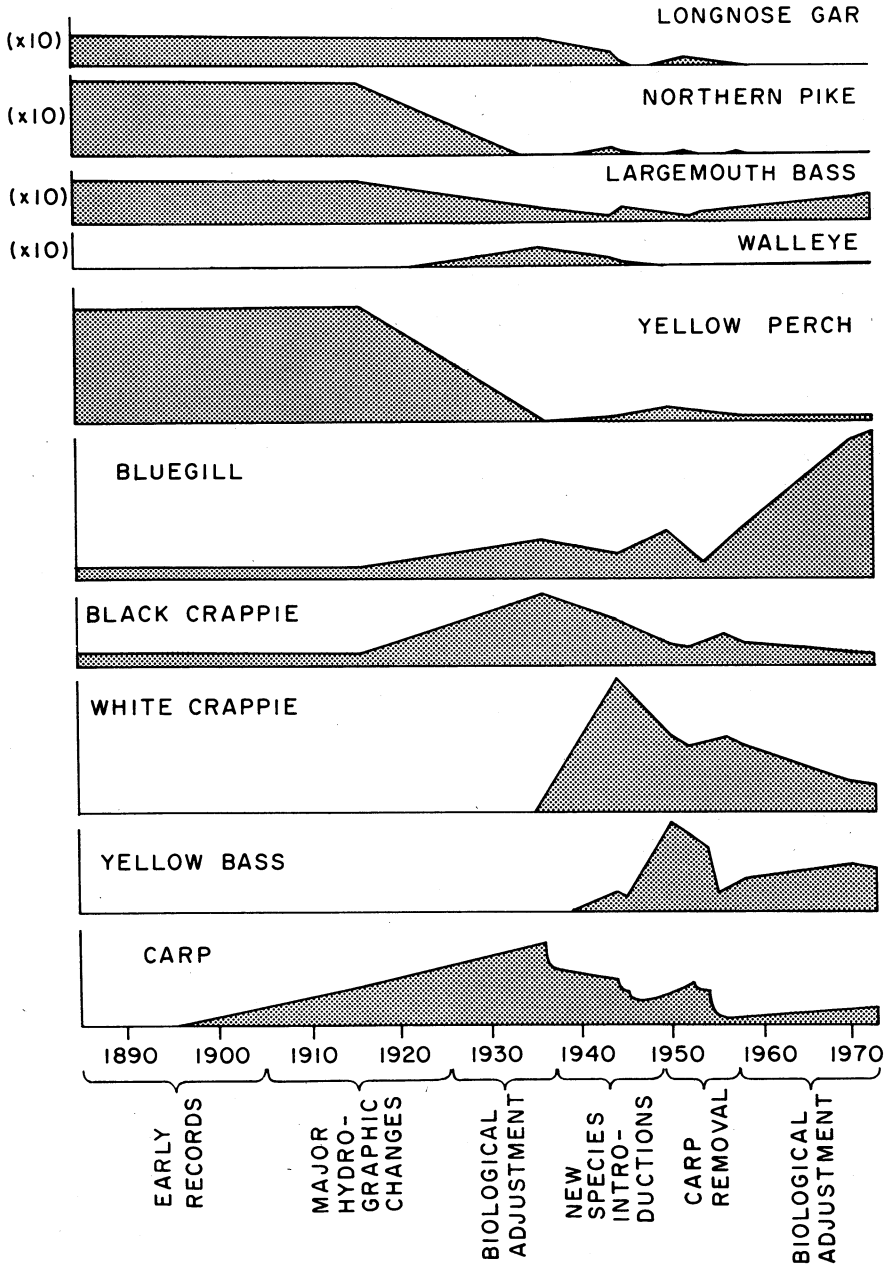

FIGURE 5. Relative abundance of major fishes in Lake Wingra from 1890 to 1973, reconstructed from the literature.

In the late 1800's, northern pike and bass were large in size and sufficiently abundant to support a recreational fishery and a food fishery for the early settlers as well as the Winnebago (Brown, 1934; Sachse, 1965).

The first perturbation by man was the introduction of carp *(Cyprinus carpio)*, an exotic from Europe. Between 1885 and 1897, 3,947 were released into the Yahara River system (Frey, 1940). Carp were first noted in Lake Wingra by Dr. Samuel H. Chase during the late 1890's, but they were not common then (Leopold, 1937).

Period of Major Hydrographic Changes (1905–1925)

Limnological investigations by A. S. Pearse and his associates and by A. R. Cahn occurred between 1914 and 1916, in the midst of the most radical hydrographic manipulations to the lake and almost 20 years after carp were first present. They viewed the fish community as similar to that of the late 1800's, but one whose characteristics were already starting to change. Several new species, introduced to the lake in the early 1900's, also contributed to these changes.

A diverse community of fish predators inhabited the lake (Fig. 4). They included northern pike, smallmouth bass, largemouth bass, longnose gar, and bowfin *(Amia calva)* (Pearse and Achtenberg, 1918). All were probably native.

In addition, walleye *(Stizostedion vitreum)* were stocked (Fig. 4) in 1900–1903, 1905–1909, 1912, 1916, 1921, and 1922. Noland (1951) assumed that walleye were native to the lake, but Helm (1958) argued that they were not because classical spawning sites of wave-washed gravel were lacking. Preigel's (1970) observation of walleye spawning in flowing deep marshes suggests that alternative spawning sites were present in early Lake Wingra. Since 2,655,000 walleye had been stocked eight years prior to any species other than carp, and since they were not mentioned prior to 1900 even though they were a favored game fish, and since they were not caught in gill nets set by Pearse and Achtenberg (1918), we conclude that they were not native to the lake.

The most abundant predator (Fig. 5) was northern pike, which was twice as frequent in gill nets as the basses (Pearse and Achtenberg, 1918). Although northern pike are more vulnerable to gill nets than bass, early accounts of Lake Wingra's fishery seem to agree that northern pike had the larger populations. Largemouth bass were only slightly more numerous than smallmouth bass. Longnose gar were quite abundant in 1914 (Brown, 1915).

In 1922, the Wisconsin Conservation Department recorded that 3,000,000 "pickerel" fry had been stocked in Lake Wingra (Lake

Wingra file, 1972). They were most likely northern pike as interpreted by Noland (1951); none of the later surveys have recorded true pickerel present in the lake.

Medium predators on invertebrates and fish (Fig. 4) included the yellow perch, black crappie, bluegill and pumpkinseed *(Lepomis gibbosus)* (Pearse and Achtenberg, 1918). All were probably native. Green sunfish *(Lepomis cyanellus)* were not mentioned by Pearse and Achtenberg (1918) nor by Cahn (1915), but were found in the 1950's and are often common to this type of habitat. We speculate that they were native but not common.

Yellow perch was the most common fish in the lake (Fig. 5). Pearse and Achtenberg (1918) caught with gill nets 14 times more yellow perch than the next most common species. They were small, mean length ca. 15 cm, which may explain lack of their mention in early fishing records. Interestingly, fingerling perch were stocked in 1915 and 1917 despite their abundance and apparent poor growth.

Pearse (1918) believed black crappie were more abundant than bluegill and pumpkinseed, based on inshore dipnet catches, but bluegill were slightly more frequent in his gillnets (Fig. 5).

The brown bullhead, *Ictalurus nebulosus,* was abundant (Cahn, 1915; Pearse and Achtenberg, 1918). While Noland (1951) believed these were misidentified yellow bullheads *(Ictalurus natalis),* this seems unlikely because Pearse was a limnology professor and a professional fisheries expert employed by the Bureau of Commercial Fisheries. The brown bullhead was likely a native.

Small predators on invertebrates (Fig. 4) included golden shiners *(Notemigonus crysoleucas),* abundant in the gillnets set in the lake (Pearse and Achtenberg, 1915); and, in the springs, spring pools and streams, the blackchin shiner *(Notropis heterodon)* and blacknose shiner *(Notropis cayuga)* (Cahn, 1915); the bluntnose minnow *(Pimephales notatus)* (Pearse, 1918); the central mudminnow *(Umbra limi)* (Cahn, 1915; Pearse, 1915); the banded killifish *(Fundulus diaphanus)* (Cahn, 1915; Pearse, 1916); the brook stickleback *(Calea inconstans)* (Cahn, 1915; Pearse, 1918); and the johnny darter *(Etheostoma nigrum).* While most of these were probably native, some may have been introduced by fishermen using them as bait.

The introduced carp had by that time become common (Cahn, 1915; Pearse and Achtenberg, 1918).

Period of Biological Adjustment (1926–1936)

Other than by a growing sport fishery, Lake Wingra was little altered by new human influences from 1926–1939. Instead, the fish community was adjusting to earlier hydrographic manipulations and introductions of walleye and carp. Carp rose to dominance by the 1930's and a state supported program of carp removal began.

In 1936 the Wisconsin Conservation Department made two seinings in Lake Wingra to remove carp and other rough fish. The seinings also provided a valuable record of changes occurring between University studies in the 1910's and in the 1950's. The large-mesh seines only provided estimates of larger fishes, and even these estimates must be inaccurate owing to the technical difficulties involved in a large seine haul. Although the same fish predators inhabited the lake as during the early 1900's (Fig. 4), a marked decline in abundance of northern pike had occurred (Fig. 5). Based on the two seine hauls, longnose gar was the most abundant predator (2,500 caught); black bass (1,100 caught), and walleye (1,000 caught) were also abundant. As before, largemouth bass were slightly more abundant than smallmouth bass. Bowfin and northern pike were uncommon, with only 11 northern pike captured (Noland, 1951).

The decline of northern pike (Fig. 5) was most likely a direct result of reproductive failures owing to the hydrographic changes of the 1910's which had all but eliminated spawning marshes connected to the lake (Figs. 1 and 2A). Northern pike spawn in early spring in marsh areas, usually only 30–60 cm deep. The increase in walleye, a potential competitor, and the decline in yellow perch, a favored food, may also have contributed to the decline. The abundance of walleye was probably a result of stocking 2,466,000 fry between 1928 and 1930. Approximately 10,000 black bass fingerlings had also been stocked in 1930.

Longnose gar and bowfin were in 1936 considered "rough fish" and those caught in the seines were not returned to the lake. Longnose gar are primitive fish with low reproductive potential and would be significantly reduced by seining. Thus seining contributed further to a decline of fish predators in Lake Wingra.

A major change in abundance among the medium predators on invertebrates and fish (Fig. 4) was also detected with the seine hauls. Crappies *(Pomoxis)*—40,000 caught, sunfish *(Lepomis)*—20,000 caught, and a new species, the white bass *(Morone chrysops)* —1,500 caught, were most common and bluegill was the primary sunfish (Juday, 1938). White bass was an introduced species with 900 stocked in 1917 and 1000 in 1933. The yellow perch, which was the dominant fish species of the early 1900's, was no longer even common. Another new species, the bigmouth buffalofish *(Ictiobus cyprinellus)*, was caught for the first time. Juday (1938) reported 300 from the hauls. Noland (1951) believed bigmouth buffalofish were native. Pearse did not mention them in his rather thorough study, but they might have been present because the marsh area between Lakes Wingra and Monona would appear to be a good site for spawning. On the other hand, they may have immigrated to the lake in 1917–1919 when the southeast dike was open to Lake Monona.

The introduced carp, the stimulus for all the seining, was abundant (Fig. 5) and 6,000 were caught and removed. By weight, their 20,000 kg exceeded the weight of all other species caught.

Period of Intense Species Introductions (1937–1949)

By the 1920's, three new species had been intentionally introduced: the carp in the 1880's, the walleye, first in 1900, and the white bass, first in 1917. Between 1935 and 1945, the Wisconsin Conservation Department stocked 20 to 23 different species of fish depending on what species the categories of sunfish and bullhead contained. Some of these were new to the lake. Even three cold water species of trout, totally unsuited to Lake Wingra, were stocked from 1934 until 1941 (Fig. 4). The total array of fishes for stocking came both from hatcheries and from fish rescue operations.

Fish rescue, intensely practiced, was unique to the upper Mississippi drainage basin in the 1930's and 1940's. After periodic floodings of the Mississippi River, large number of fish were often isolated from the river and trapped in temporary ponds when the river waters receded. These fish were "rescued" by federal authorities, held in hatcheries and later stocked. Mr. Charles Lloyd of the Wisconsin Conservation Department, who was interviewed by Noland (1951), stated that fish species other than those actually recorded had most likely also been stocked. Also, prior to 1941, federal fish rescue and transfer operations were carried out independently of the state, and private individuals or organizations could apply for a shipment of fish and stock it wherever they wished (Noland, 1951). Records of introduction would not exist.

The continuation of the removal program in 1944, 1945 and 1949, and fyke and gill nettings by Noland and Neess from 1944–1947 provide fairly good indication of the composition of the fish community in the mid-1940's. All seining data are from Noland (1951). He originally obtained them from the Wisconsin Conservation Department's records. Carp and bowfin were removed from the 1944, 1945, and 1949 seinings. After 1945, longnose gar were returned to the lake if caught.

The fish predator community (Fig. 4) still contained longnose gar, largemouth bass, northern pike, walleye, and bowfin, but the smallmouth bass was rare and a new organism, the northern pike-muskellunge hybrid *(E. lucius* x *E. muskelunge),* was present in low numbers.

The relative abundance (Fig. 5) can be judged from 1944 and 1945 seine hauls. The 2-year combined hauls yielded 1154 longnose gar, 297 black bass (probably largemouth), 170 northern pike and 162 walleye.

Overall, fish predators seemed less abundant than in 1936. In addition, longnose gar were declining rapidly, as only 154 were taken during the 1945 haul. Thereafter, they were no longer removed in seining operations. Both walleye and bass populations had dropped since 1936, even though walleye had been stocked in 1940 and 1943 (7,000,000 fry being stocked in 1943 year alone), and largemouth bass had been stocked in every year from 1937 to 1944. Largemouth bass declined again through 1949 (Helm, 1958). Perhaps the large numbers of walleye fry stocked in 1943 were too small to be abundant in the seine hauls one and two years later, but they were also uncommon in the 1949 seine hauls. The northern pike were more abundant than in 1936 and were probably the result of the stocking that occurred in 1940, 1941 and 1942, as indicated by their average weight of 1.5 kg. Since no further stocking was conducted, northern pike, without significant spawning areas, started to decline again in the late 1940's. The northern pike-muskellunge hybrids were stocked in 1940, 1945, 1946 and 1948. They did add to the sport fishermen's catch and were caught in low but steady numbers during the seine hauls. The collapse of the smallmouth bass population has not been explained, but might have been related to the expanding populations of medium predators on invertebrates and fish. Noland (1951) suggested from his observations that illegal removal of bass from above the dam during the spawning season may have contributed to the decline.

The community of medium predators on invertebrates and fish increased during the late 1930's and the 1940's. In addition to black crappie, bluegill, pumpkinseed, white bass, and yellow perch, two new species were noted—the yellow bass *(Morone mississippiensis)* and the white crappie *(Pomoxis annularis)* (Fig. 4).

Marked changes occurred in the relative and absolute abundances of the above species (Fig. 5). As a group, they were more abundant than in 1936. The magnitude of the catch during 1944 was much greater than expected by the Conservation Department (Noland, 1951). Dr. Black had intended to have all individuals counted, but the haul took two days to empty and during the night large groups of fishes other than carp were allowed over the net. Regardless, Dr. Black estimated that in 1944, the following adult fish were caught: 350,000 white crappie, 100,000 black crappie, 50,000 bluegill, 40,000 yellow bass, and 10,000 white bass. In addition, pumpkinseed had a relatively large population and yellow perch were still present, but low in abundance.

The high numbers of white crappie and yellow bass in the catch were especially surprising, since they had not been reported before. Based on records from Buffalo Lake reported by Helm (1958), yellow bass are favored by the water quality and vegetation changes that go along with high carp abundance. Perhaps some of the crappies caught in the 1936 carp seine hauls were white rather than black crappie. Regardless, white crappie reached their large population level (and greatest abundance) within approximately ten years, and this entire group of seven fishes, excluding yellow perch, had become abundant. Even so, this period was characterized by intensive stocking of some abundant species and a continually declining fish predator population.

Many fish of these seven species were stocked intentionally or unintentionally during fish rescue operations—crappies in 1940, 1941 and 1943, bluegill in 1939, 1940, 1941, 1943 and 1944, white bass in 1940 and 1943, and yellow perch in 1938, 1939 and 1940. White crappie and yellow bass were not recorded specifically in the stockings, but crappies stocked were not noted to species.

In addition to the native brown bullhead, two species in the catfish family were noted (Noland, 1951) for the first time: the yellow bullhead, and the channel catfish *(Ictalurus punctatutus)* (Fig. 4). Unidentified bullheads were stocked in 1930, 1939, 1942, 1943 and 1945, totaling 40,000 fingerlings, 10,000 yearlings and 2,600 adults.

The bullheads were present in moderate numbers in the seine hauls and most were yellow rather than the brown bullhead (Fig. 4). Channel catfish never flourished (only one to three were caught per seine haul during the 1940's).

Three other new species common in the Mississippi River were first found in the 1944 and 1945 seine and fyke net studies: the common white sucker *(Catostomus commersonii),* the spotted sucker *(Minytrema melanops),* and the northern redhorse *(Moxostoma macrolepidotum)* (Fig. 4). Six adult suckers were recorded as stocked in 1940. Common white suckers apparently reproduced: 75 were caught in 1944 and 120 in 1945. Thereafter they declined. Northern redhorse persisted in low numbers (one to three per seine haul) for a number of years, but only one spotted sucker was caught in a single seine haul.

Bigmouth buffalofish were caught, but only in low numbers (Fig. 4). Carp remained abundant (Figs. 4 and 5), with about 3,000 caught in the 1949 haul.

Entering the 1950's, the lake contained at least nine species not present prior to the 1880's. These species included not only the abundant carp, but also the most abundant and fourth most abundant zooplankton and macro-invertebrate feeders—the white crappie and yellow bass. In addition, the black crappies and bluegill had increased in numbers. Fish predators were declining, with the primary predator—the northern pike—apparently requiring continual artificial replenishment, since its original spawning areas were reduced or eliminated.

Period of Intense Carp Removals (1950–1959)

An intensive and effective carp seining program was instituted by the Wisconsin Conservation Department between 1953 and 1955 because earlier efforts had not reduced the population to low enough levels. After each of 14 seine hauls in the 1950's, the number of carp remaining in the lake was calculated with mark and recapture techniques and by the depletion of the residual population (Neess, Helm, and Threinen, 1957). Records from these seinings for large fish and a major study by Helm (1958) using trawls, fyke nets and small mesh seines for smaller species provide good data on the fish community during the early and mid-1950's.

The same large fish predators were present (Fig. 4) as in the 1940's, but, among the predators, only largemouth bass were increasing in abundance (Fig. 5). Largemouth bass entered the 1950's at low to moderate population levels. Seinings in the early 1950's revealed a sharp increase in their population (Lake Wingra Files, Wisconsin Department of Natural Resources, 1971). Large to good hatches occurred from 1954 to 1956 (Helm, 1958). Scientific collections and angling indicated further increases in the late 1950's.

As many as 480 longnose gar were caught in three seine hauls in 1952–1953, but by 1955 none were caught in six hauls (Lake Wingra Files, Wisconsin Department of Natural Resources, 1971). Helm (1958) noted that they continued to decline even though returned to the lake after each seine haul. Thus longnose gar joined the smallmouth bass as an extinct or rare native predator in Lake Wingra (Figs. 4 and 5). Smallmouth bass were listed as present by Helm (1958), but none were mentioned from any of the seine hauls.

The low populations of both walleye and northern pike continued to decline. Based on seine hauls, the northern pike fell to a new low (Fig. 5). According to Helm (1958), marshes along north central and western shorelines had virtually been filled in by natural sedimentation in recent years to even further restrict spawning to three limited areas, only one of which was large enough for many young. Northern pike was the only species stocked in the 1950's—4,500, largely from the 1956 hatch, were stocked in January, 1957. Helm stated some limited natural reproduction of walleye was occurring, but the lake did not have any traditional spawning habitats. Walleye were seldom caught by sport fishermen or in the seines.

Bowfin and northern pike-muskellunge hybrids were caught in low numbers in the seinings throughout the early 1950's. The hybrids, last stocked in 1948, were still present in 1955.

The same medium predators on invertebrates and fish were present as in the 1940's (Fig. 4). In order of decreasing abundance (Fig. 5) they were: white crappie, bluegill, black crappie, yellow bass, and yellow perch. White bass, pumpkinseed and green sunfish were low in abundance, and hybrids with their close relatives were noted.

Populations of white crappie, bluegill, and black crappie were observed in Helm's careful study to fluctuate from year to year (Fig. 5). Three trends were perhaps evident, though: an increasing abundance of bluegill from 1954 to 1958, a decline in white bass, and a decline in the welfare of the yellow bass population. Bluegill seemed to be favored by the increased vegetation after carp removal, with good hatches in 1954–1956. Yellow bass were abundant in 1953 and early 1954, but high mortalities occurred during 1954. In a letter dated June 27, 1955, referring to carp removals, Elmer Herman, then Area Coordinator for the Fish Management Division of WCD, wrote: "We are already observing great increases in the amount of rooted vegetation, decided deterioration of the yellow bass and increases in the number of bass and bluegills" (Lake Wingra File, Wisconsin Department of Natural Resources, 1971). Yellow bass numbers were at a low point in late 1954 and 1955. By 1957, yellow bass numbers had substantially recovered, but the new population of yellow bass was noticeably stunted (Table 3). Although the numbers of yellow bass had returned to a high level, their biomass remained a great deal less (Helm, 1958).

By this time three bullheads were present: the yellow bullhead, the brown bullhead, and the black bullhead *(Ictalurus melas)*. The

TABLE 3. AVERAGE TOTAL LENGTHS OF YELLOW BASS BEFORE AND AFTER INTENSIVE CARP REMOVAL PROGRAMS IN LAKE WINGRA. ADAPTED FROM HELM (1958)

	Total Body Lengths (mm) Before Carp Removal	After Carp Removal
Age (Years)	(1945–1946)	(1954–1957)
One	179	135
Three	232	160

yellow bullhead was most common. Helm (1958) still listed channel catfish, common white sucker, and northern redhorse as present.

Bigmouth buffalofish were more abundant in the seine hauls than earlier: 71 in 1952–1953, 125 in 1954, and 45 in 1955 (Lake Wingra File, Wisconsin Department of Natural Resources, 1971).

Carp were greatly reduced during the 1950's. From the mark-recapture data, the carp population was estimated at 27,837 fish prior to the start of the control program in 1953. By the end of 1953 (two seine hauls), the number had been reduced to 23,321. By the end of 1954 (six seine hauls), the estimate was 5,585, and, by the end of 1955 (six seine hauls), 2,698. Not all mortality was from fishing. Natural mortality losses (especially over winter) approximately equaled the yield to seining. Also notable was the lack of reproduction by the carp population. Follow-up studies in 1956 consistently failed to find any young carp, indicating a further decline in the population (Neess, Helm, and Threinen, 1957). Helm (1958) computed the number of carp in Lake Wingra as of March, 1957, at 685 to 2,174 fish.

A comprehensive list of small predators on invertebrates was also presented by Helm (1958). These included the species mentioned by Cahn and Pearse in the 1910's, except for the mudminnow and the blacknose shiner. The golden shiner was at a moderate population level in the lake. Four new species were reported: the lake emerald shiner *(Notropis atherinoides)*, the satinfin shiner *(N. analostanus)*, the central common shiner *(N. cornutus)*, and the Iowa darter *(Etheostoma exile)*. These may have been overlooked by the earlier investigators, may have invaded the lake during 1917–1919, or they may have been introduced as bait minnows. Helm does not state that any of these species were abundant, only that they existed.

The fish community entered the 1960's with few carp, a declining predator population except for the largemouth bass, and an abundant and diverse community of medium predators on invertebrates and fish. The lake had begun to respond to the absence of carp and rooted aquatic macrophytes were expanding in the littoral zone.

Second Period of Biological Adjustment (1958–1973)

In this period no major modifications by man were initiated and the lake's fauna again had time to come into a new equilibrium. An intensive study of the fishes primarily through the International Biological Program (see INTRODUCTION) from 1966 through 1973 documented fish community structure 11 to 18 years after the completion of carp removal, 35 years after the massive species introductions, 50 years after large reductions in adjoining marsh land, and 100 years after white settlers first inhabited the watershed.

Fishes were sampled by trawls, fyke nets, electrofishing, and beach seine (Magnuson and Kitchell, 1971; Baumann, 1972; Churchill and Magnuson, 1972; El Shamy, 1973; and Baumann and Kitchell, 1974). Population estimates by mark and recapture were begun in 1972. In all activities, approximately 500,000 fishes were captured, identified and enumerated.

The fish predator community only included largemouth bass and northern pike (Fig. 4) as far as any practical influence on the ecosystem is concerned. Walleye, longnose gar and bowfin were rare. Smallmouth bass were absent entirely from the catches.

Largemouth bass were the most abundant predator (Fig. 5) and were the third most common species taken by electrofishing in 1970. Angling pressure was low, but good catches of large bass were not uncommon. Young fish were frequently taken in samples from the littoral zone indicating successful reproduction.

Northern pike continued to decline since stocking ceased in the late 1950's. They were rare in anglers' catches and young were rare in any sampling gear. Fyke nets during early spring, 1973, captured a few northern pike representing several size classes (Churchill, personal communication). Redwing Marsh (Fig. 1) has provided the only suitable spawning habitat in recent years.

Two adult walleye were caught since 1970. They probably are limited by suitable spawning sites and represent residuals from past stocking. Only an occasional bowfin was caught and two longnose gar were caught in a fyke net in 1972. Smallmouth bass were occasionally reported by fishermen in the early 1960's, but none have appeared in surveys or in the sport fishery since then.

The medium predators on invertebrates and fish remained diverse and, in decreasing order of abundance, included bluegill, white crappie and yellow bass, black crappie, pumpkinseed, yellow perch, and green sunfish (Figs. 4 and 5). White bass had disappeared. The abundance (Fig. 5) of several species had changed markedly since carp removal and the redevelopment of dense littoral macrophytes. Bluegill and pumpkinseed both increased greatly and yellow bass increased slightly. Both white and black crappie decreased in numbers. Yellow perch remained stable but low. Green sunfish had apparently increased to a low but noticeable population level.

Bluegill were by far the dominant fish species, comprising well over one half of all fish caught during 1970 and 1971. Large numbers of young-of-the-year bluegill indicated successful hatches in every year except 1972. Churchill (personal communication) recalculated population numbers for the total lake (Churchill and

Magnuson, 1972) to account for sampling bias and marking mortality. Yearling bluegill were estimated during May, 1972, to have been approximately 3,000,000 fish; subadults (II+) about 800,000; adults (III+ to V+) about 340,000.

Bluegill were numerous, but stunted (Fig. 6) or characterized by poor growth (El Shamy, 1973; Kuczynski, unpublished) compared with earlier years (Helm, 1958). The reduced growth began to appear in 1955–1957, immediately after completion of the carp removal, and by 1970–1972 was even lower (Fig. 6). At annulus I total lengths seemed comparable, but by annulus V the average length had declined by 25% over the 25 years since 1945–1946. In terms of body weight this translated to a reduction of approximately 70%.

Yellow bass adults were estimated by Churchill (personal communication) to be about 50,000 in May, 1972, and were second only

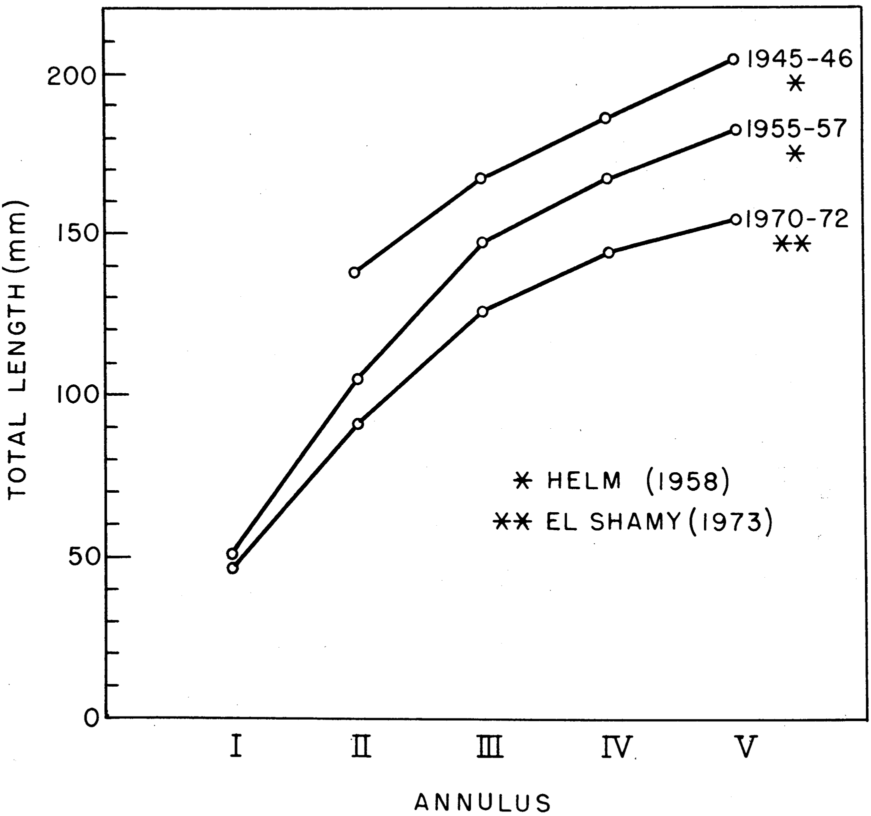

FIGURE 6. Body growth curves for bluegill in Lake Wingra before, during and after the successful carp control program of the early 1950's.

to bluegill in numbers caught during 1970 surveys, with 9,933 caught. The yellow bass after carp removal immediately began to stunt (Table 3) and remained stunted through the 1960's. Surveys in 1968–1973 rarely captured yellow bass larger than 175 mm.

No white bass were captured from 1968 to 1973; they were most likely ecologically replaced by yellow bass with the last members genetically swamped out of existence by the hybridization noted in earlier periods. A similar replacement has been occurring in the other Madison lakes (Wright, 1968).

White crappie adults were estimated (Churchill, personal communication) to be approximately 50,000 fish in May, 1972, and over 4,700 were captured in the 1970 surveys. Adults of this open water centrarchid appeared stunted, usually no longer than ca. 190 mm.

Black crappie were the most common fish in samples from the littoral zone in 1970—1,114 out of 4,308 fish captured. On the other hand, only 492 of the 42,160 fish caught by trawls in the pelagic zone were black crappie. Overall they were the fifth most common species caught in the surveys, with 1,606 captured. As noted by Helm (1958), the two crappie species spatially segregate with black crappies concentrated in the littoral zone and white crappie concentrated in the pelagic zone. In the 1965–1973 surveys, adult black crappie were also stunted, usually no longer than ca. 185 mm.

On rare occasions we have observed large white crappies and black crappies (ca. 300 mm-400 mm), suggesting that a few become large enough to feed routinely on young fishes.

Pumpkinseed adults and subadults in May, 1972, were estimated to total 28,000 by Churchill (personal communication), and were fourth in abundance in the 1970 survey, with 2,950 captured. While this may be an overestimate of their actual relative abundance, they were certainly among the five most abundant species and were apparently favored by the carp removal. Also in the 1970 surveys, 195 yellow perch and 30–40 green sunfish were caught.

All three bullheads remained (Fig. 4), but by the late 1960's black bullheads and yellow bullheads were equally abundant in catches and the native brown bullhead was rare. No channel catfish were caught or reported during the period; they have probably become extinct in this lake.

Neither bigmouth buffalo nor northern redhorse were reported during the period and were likely extinct in this lake. Common white sucker were captured singly and infrequently. They exist in low numbers.

Carp populations were moderate and had not returned to high levels after the removals in the early 1950's. Only 58 of the 46,500 fish captured in 1970 were carp. With only several exceptions, all carp were large, mature fish even though the gear would more likely have captured smaller fish. During one 24 hour electrofishing survey in shallow areas during September, 1970, no young-of-the-year or yearling carp were caught, even though 1,200 young-of-the-year bluegill were captured (Baumann, 1972). Apparently reproduction by carp has been relatively unsuccessful in recent years, but we cannot exclude the possibility that they may be slowly increasing. After first being noted in the lake just prior to 1900, they were not common until the 1910's nor abundant until the late 1920's or early 1930's.

Small predators on invertebrates in the lake proper included golden shiner, silversides and bluntnose minnows. Golden shiners were abundant—280 were caught in the 1970 survey. Silversides were also caught in moderate numbers.

While the surveys from 1968–1973 did not concentrate on the springs, spring pools and tributaries, the mudminnow was again caught in the tributaries. Surprisingly, this is one of the two smaller species mentioned by Cahn (1915) that Helm (1958) did not find. Some of the other small species listed by Helm (1958) may still be present but are not abundant in the lake proper.

The fish community of Lake Wingra proper entered the mid-1970's with 20 species of fish. Of these, only 12–14 species were probably native to the lake. In the period of adjustment after carp removal, carp remain low in abundance, predators remain low in abundance, and invertebrate feeders are characterized by poor body growth. The lake is not a major protein source to the city around its shores but children enjoy a high catch rate of small bluegill, pumpkinseed, yellow bass, and crappies during summer vacations. Fishing through the ice in early winter provides some of the better sport fishing.

SUMMARY AND CONCLUSIONS

Man's activities in the Lake Wingra basin dominate its history. Indians used the region as a major hunting and fishing ground. Homesteads did not appear in the Wingra watershed until the late 1860's, and the area remained isolated past the turn of the century. From 1905 to 1920, major physical alterations of lake and surrounding wetland were made. Urbanization of the north shore followed the development of Nakoma and Madison from about 1910.

The original hydrography of Wingra before alteration by man was different than now. Water level was about 0.3 m higher. Gardner Marsh and upper Murphy Creek were originally part of an extensive shallow area at the east and southeast end of the lake. Shoreline extended beyond the lowland, now part of Vilas Park.

Wetland surrounding the lake also covered a wider area. Maximum depth was about 4.3 meters.

In 1905 man began to engineer changes in the hydrography of the basin. Years of activity at the east and southeast end of the lake resulted in the isolation (from the lake) and partial drainage of an area, now Gardner Marsh. Murphy Creek was channeled and lowered below lake level after the present spillway dam was built. From 1917 to 1919, the lake's level was lowered about 1.3 m below the original; reduction of surface area resulted. After dam construction, the lake was raised 1.0 m to its present level. Material dredged from the lake and creek were used to fill southern wetland. Dredging created a deep trench off of the south shore. This has partly filled, giving the lake its present maximum depth of 6.4 m. Construction of Vilas Park reduced surface area and altered the northeast shoreline. After 1920, the only major hydrographic change in the lake proper was the formation of Ho-nee-um Pond. Lake and contiguous wetland areas were reduced by a factor of three. Urbanization within the basin resulted in the disappearance of 28 springs; major changes in soil and vegetation types; and the development of a storm sewer system that carries surface water and allochthonous matter to the lake's periphery from much of the drainage basin.

Original aquatic macrophyte vegetation around 1900 differed in type, abundance and distribution from the present. Cattails and bulrushes dominated shallow areas; wild rice abounded in slightly deeper water. Submerged vegetation included water celery and pondweed.

Dredging operations destroyed vegetation directly and indirectly. Fluctuations in water level had detrimental effects. Hydrographic alterations reduced the area available for littoral growth. From the late 1920's to the mid-1950's, carp nearly denuded Lake Wingra of macrophytes. After an extensive carp removal program, vegetation returned, but it was of a different nature than the original. Lake Wingra's vegetation is now heavily dominated by a non-native species, Eurasian water milfoil *(Myriophyllum spicatum)*. Wild rice, wild celery, and several other native species are no longer present.

Major changes in habitat and heightened predation pressure from increasing fish populations resulted in substantial reductions of invertebrate populations. Many species of zooplankton are no longer found in the lake while others, and some macroinvertebrates such as *Hyalella azteca*, have been reduced to virtual extinction.

Fish populations in Lake Wingra have changed continually. Species native to the lake in 1900 included bluegill, pumpkinseed, black crappie, largemouth bass, smallmouth bass, longnose gar, yellow perch, northern pike, bowfin, golden shiner, brown bullhead, and possibly the bigmouth buffalo and walleye. Largemouth bass, yellow perch, northern pike and walleye populations have declined. Longnose gar, smallmouth bass, bowfin and bigmouth buffalo are actually or functionally extinct from the lake.

Changes in the native fish fauna can be partly explained by the reduction of littoral areas due to hydrographic alterations and the activity of carp. Selective fishing and the introduction of exotic fish also played a role. The fish rescue-and-transfer operation was an unfortunate outgrowth of the early conservation ethic, which was gaining popularity during the 1930's in Wisconsin. Reclaiming these fish was considered beneficial in itself. The benefits of stocking fishes in a lake was an accepted truth of the time, and little effort was made to correlate specific species with habitat requirements. Among the 23 species stocked into Lake Wingra, two—yellow bass and white crappie—have become abundant.

Both largemouth bass and bluegill populations have recovered, since the carp population was controlled in the 1950's. The bluegill responded by becoming the dominant species in the lake. This increase together with the establishment of white crappie and yellow bass have produced the large, stunted panfish population which characterizes the present sport fishery.

Other contributors to the increase in panfish populations were, first, the decline of native fish predators and, recently, the dense aquatic vegetation that even further reduced the effectiveness of those predators remaining. The depletion of both the gar and the northern pike appeared to be independent of carp abundance per se. Gar were reduced by rough fish removal aimed primarily at carp, but the presence of a large carp population did not seem detrimental to the gar population. Northern pike decline is closely linked to destruction of suitable spawning habitat.

Wingra, like most lakes, has never been managed as an ecosystem, but rather individual problems have been attacked one at a time. To diversify the angling and reclaim fish, new species were introduced. Little thought was given at the time as to whether these species could thrive or to whether they would negatively influence native species. Marshlands were drained for park and land development, and the reproductive success of higher predators was severely reduced. Carp were first introduced into our waters, then became a nuisance and were actively removed. Again, the secondary effects of carp removal were not anticipated.

To be effective, management plans must consider the entire fish community and the total ecosystem. The historical perspectives described in this paper serve as illustration of the complex interactions and response capabilities of a total ecosystem. An integrated whole ecosystem approach is essential in establishing ecologically sound management. Although resources are often not available to make an overall ecosystem study, sound management would seem to require consideration of as many interactions and secondary effects as time, funding, and contemporary knowledge and techniques permit. As always, hindsight is better than foresight, which probably explains why the next chapter of this article is not yet written.

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A HISTORICAL SKETCH OF THE EVOLUTION OF ENERGETICS

Robert T. Balmer
University Wisconsin —Milwaukee

INTRODUCTION

Let us begin by eliminating, as much as possible, the word "thermodynamics" from our vocabulary. For we are not interested here in the "dynamics of heat" in systems which are, in every way, *static,* or what amounts to the same thing, *quasistatic.* Let us begin anew and, without trying to coin new words or phrases, accurately designate the ideas we propose to explore. We may easily title what up to this point has been called "classical thermodynamics" with simply "static energetics." Since energetics is defined as "the science of energy," static energetics is then to be taken as "the science of energy in energetically static systems." And the concepts which of late are becoming known by the unfortunate, cumbersome and inaccurate label of "irreversible" or "non-equilibrium" thermodynamics simply accept the title "dynamic energetics." Dynamic energetics is defined as "the science of energy in energetically dynamic systems." Thus energetics, like mechanics, consists of a study of statics and dynamics. But whereas in mechanics one is concerned with only the state of forces and motions of the system, in energetics one is concerned with the total energy state of the systems. Thus, in some sense, energetics includes mechanics as a subset in the hierarchy of science.

Now that we have a common terminology base, we can begin to trace the thread of energetics through time. My ultimate goal here is to establish, both historically and logically, the place of energetics as an axiomatic science which will eventually replace both classical and irreversible (or whatever) thermodynamics as a fundamental body of man's knowledge.

ANTIQUITY TO THE RENAISSANCE

The modern scientific concept of "energy" dates only from the 19th century, and the word, with the spelling used here, seems not to have been in use at all before about 1580.[1] Etymologically, the word "energy" is of Greek origin, coming from the roots *en* = "in" plus *ergon* = "work",[2, 3] and seems to date from around the Platonic era.[4] The original Greek "ενεργεια," was rendered into English[5] as "energia," with this spelling dominating until about A.D. 1600. Samuel Johnson,[6] in his unique dictionary of the English language, states:

> "I have not been able to trace our word [energy] to any author before Bacon [1626]. Sidney, in his *Defence of Poesy,* written soon after 1580, shows that it was not then in use; for he there introduces, in its stead, 'energia, as the Greeks call it.'"

A brief review of English dictionaries published from the time of Bacon reveals Thynne[7] (1599) using "energye," Cockeram[8] (1623) using "energie," and Phillips[9] (1658), Coles[10] (1696), Kersey[11,12] (1702 and 1708), Bailey[13] (1730) and Sheridan[14] (1788) all using "energy."

The meaning of the word "energy" (or "energia") up to the 19th century remained essentially unchanged from that of the original Greek usage. Aristotle (ca 384-322 B.C.) defined energia as meaning activity or actuality,[15] commonly using these concepts interchangeably.[16] His usage, and that of the civilizations that followed him, implied a concept that is much more general than the simple "in-work" etymological translation. However, Aristotle's rendering of energia as some form of undefinable "potential" is a characteristic of the concept of energy today. "The capacity for performing work" is the modern scientific definition of energy, and capacity and potential are synonymous here.

Dictionaries of the 17th and 18th centuries consider energy as synonymous with such words as strength, force, power, vigor and efficacy. If we attempt to trace the energy concept into pre-Grecian civilizations, we therefore must look for the concepts of work, strength, power and force. Indeed, there are Assyrian words[17] and Egyptian hieroglyphics[18] with exactly these meanings. However, pre-Grecian antiquity seems sadly devoid of eloquent philosophers whose works have survived to provide us with a tool for the accurate translations of abstract concepts. It is probably true that without such philosophers there is no need for words that are more than simply descriptive,[19] and thus abstract ideas will not naturally evolve easily in such cultures.[20]

DESCARTES, LEIBNIZ AND VIS VIVA

Réné Descartes (1596–1650), latinized as Renatus Cartesius, in his *Principles of Philosophy* (1644)[21,22] made reference in his laws of motion to the divine conservation of the "quantity of motion" of a body. To Descartes this quantity was the volume of the body times its velocity.[23] In 1686 Gottfried Wilhelm Leibniz (1646–1716)[24] published a strong refutation of Descartes' position. Leibniz felt that the force of a body in motion was uniquely different from Descartes' "quantity of motion." His position was that:[25]

> ". . . the forces are in compound proportion to the bodies (of the same specific weight or density) and the generating heights of the velocities . . ."

Thus Leibniz held that the force of motion was proportional to the square of the velocity. Further, he felt that there were two general classifications of forces: living forces (dynamics) and dead forces (statics). In 1695 he concludes:[26,27]

> "Force is twin. The elementary force, which I call *dead* because motion does not yet exist in it, but only a solicitation to motion, is like that of a sphere in a rotating tube or a stone in a sling.
>
> "The other is the ordinary force associated with actual motions, and I call it *living*."

This was for formal beginning of what was to be known for the next 200 years as the "vis viva" (living force) controversy.[28] Stated simply, the *vis viva* controversy is this: What is the force of motion, mv or mv^2? In a way, it is similar to the question: Which is more fundamental, mv or mv^2? These questions have *never* been resolved. In 1747 the then 22 year old Immanual Kant[29] recognized the hopelessness of resolving *vis viva.*

The controversy involves two abstract concepts, force and motion. Soon after the controversy started, scientists began to feel that the whole argument could be settled simply by an arbitrary definition. D'Alembert (1717–1783) is credited by many early historians of science with ending the dispute in 1743 in his *Traite de Dynamique* by referring to the controversy as:[30,31]

> a: ". . . dispute of words too undignified to occupy the philosophers any longer."

It is, however, evident that the dispute was neither simply one of definitions, nor was it ended by D'Alembert.[32] There are many examples in the literature following D'Alembert, wherein the controversy is taken up both philosophically and experimentally.[33] It was regurgitated most recently in the famous Ostwald–Boltzmann energetics debate of 1895.[34]

The controversy has never been resolved and the question of the ultimate fundamentality of energy vs. momentum is still occasionally raised today.[35] However, when one thinks of motion today, he thinks of $F = ma$, and not of energy. Though true that the dispute remains unresolved, the champion of mechanics, momentum, seems to have won by popular vote. Perhaps because mechanics was more abstractly axiomatic and more mathematically developed than early energetics and thus was more functional, or perhaps because man just feels more at home with mechanical concepts. But whatever the reason, energetics was off to a poor start.

Interest in the controversy finally dwindled in the late 19th century. *Vis viva* does not appear in the scientific literature later than Thomson and Tait's *Treatise on Natural Philosophy* in 1867.[36]

Scientific jargon changed somewhat in the late 19th and early 20th centuries; today the force of motion is simply not discussed by physicists. The word "force" has been reserved, in general, for the Newtonian meaning as being derived from an acceleration.[37] Momentum (Latin for "motion") was the name finally given to the quantity mv. The term which eventually received, for a short time, the label *vis viva* was mv^2. In 1804 Young[38] began calling mv^2 "energy," and Rankine[39] in 1853 dubbed it "actual" or "sensible" energy. Its final name "kinetic energy," was given by Thomson and Tait[40] in 1862.

Thus energetics was born in controversy, in opposition to the worst possible opponent, the established monarch, mechanics. There were two crucial events which would determine the superiority of the stronger. The first was the consequences of the rise and fall of the caloric theory of heat; the second was the tremendous success of what was later to be called, "statistical mechanics."

HEAT

The failure of the caloric theory of heat was a crippling blow to the 19th century energetists. Though they alone were not responsible for inflating the theory to a position of scientific importance, when it collapsed under the strain of attacks by experimentalists they bore the consequences and suffered the humiliation of a not-so-obvious error. The fall of the caloric theory and the preceding century and a half of confusion caused by the *vis viva* debate forced the energetists onto their scientific knees. The final defeat of the 19th century energetists came from the statistical mechanics of the Boltzmann atomists. They claimed that many of the results of static energetics could be derived from statistical mechanics. Thus energetics was reduced to mechanics, and therefore it contained nothing new or unique.

By the end of the 19th century the word "energetics," connoting at that time *vis viva* and caloric, both lost battles, had fallen into disrepute and ultimate disuse. It is only now, almost a century later, when all of these scientific calamities have been forgotten, that the word is once again becoming popular.

Since the dawn of science there have been two rival theories on the structure of matter: the atomist versus the continuumist. And, like the *vis viva* controversy, this dispute over the nature of matter goes unresolved today.

This may surprise some, for who today can deny the existence of atoms? But a continuumist will say, "give me your most fundamental atomic particle, one which you are convinced is made up of no others, and I will ask you—of what does this particle consist?" "The answer can only be: a continuum." And an atomist will reply, "The question of the internal structure of an atomic particle is meaningless—it does not enter into the microscopic or macroscopic behavior of nature, and therefore is of no interest." And there the debate stagnates.

This antipathetic dichotomy reveals itself most clearly in the modern "duality principle" of the structure of matter. Here we experimentally observe that atomic particles sometimes behave like mechanical particles, and sometimes as a continuum. This paradoxial situation is analogous to the position of the caloric theory as a result of the friction experiments of Rumford and Davy at the beginning of the 19th century.

The caloric theory of heat was a natural branching in the theory of the ether (or aether). The word "ether" is also of Greek origin (αιΘηρ) and means "clear sky" or "upper air."[41] Since Aristotlean physics forbade the existence of a vacuum, it was necessary to fill all space with something, something that behaved like a fluid. Soon it was realized that light streaming through the clouds must somehow be associated with that imponderable fluid that fills all space. The analogy was quickly drawn between the light-ether and the sound-air systems. Thus light, like sound, was explained as vibrations of the propagating medium. And what about heat? If one holds his hand up to a fire, can he not feel the heat pouring out? There was no doubt that heat was also associated with the ether.

Descartes was the first to begin to quantitize and to assign properties to the ether. Before his time the ether was used only in the Aristotlean sense as a space filling fluid. In matters of ether, Descartes was an atomist. He postulated that it was made up of minute particles that were continually in motion. But since there could be no empty space whatsoever (i.e., no vacuum), the motion of these particles was complex indeed, with a moving particle always entering the space which was simultaneously being vacated by another particle.[42]

Descartes' concepts of light were soon replaced by those of R. Hooke, and Hooke's by Newton's and Newton's by Huygen's, and so on until the modern theory of light as being the result of subtle particles, now called quanta, was evolved.

By the middle of the 18th century, light was considered to be composed of minuscule "corpuscles," which move through the ether. About this same time a third branch of the ether concept was developing in the area of electricity. By 1750, the experimental work with electric "currents" led to the introduction of an electric fluid, the "effluvia," which had its own properties. But before 1800 the laws of charge, attraction and repulsion had been discovered, and effluvia was discarded in favor of the original ether, which was now thought to be decomposable into the subtle fluids necessary to explain all electrical phenomena.

A fourth branch of the ether concept was developed in 1679 by George Ernst Stahl.[43] Stahl invented the word "phlogiston" (Greek: flame) to describe his fire principle of combustible materials. All such materials were supposed to be composed of a calx (ash) in combination with phlogiston. During combustion the phlogiston escaped from the material leaving only the ash behind. Lavoisier is usually credited with delivering the death blow to Stahl's theory some 100 years after its introduction.

There were, of course, other manifestations of the ether. The magnetic fluid was one. And then there was perhaps the most subtle ether of all, the "vital spirits" contained by living organisms. The elusive vital spirits were all that separated life from death, like the soul.

At first heat and light were taken to be the same corpuscular entity. However, the discovery of the "green house effect," in about 1750, established that these two phenomena could not be simply different manifestations of the same fluid. In 1789 Lavoisier[44] introduced the word "calorique" to denote the ether of heat. During the second half of the 18th century caloric was generally conceived to be the substance which occupied the interstices between the particles of ponderable matter (atoms).

Near the end of the 18th century Rumford and Lavoisier established that the temperature of a body has no measurable effect on its weight. Rumford and Davy then established that caloric was not a conserved quantity as had been previously thought.[45] This was the beginning of the fall of caloric.

The atomists had a ready explanation. There had been an atomic theory of heat for some time. To the atomists, heat was the result of vibrations of the minute particles of matter. The rubbing of two objects together simply caused these minute particles to vibrate faster, and heat was directly proportional to the particles' vibration.

In 1824 Sadi Carnot, a 28 year old French military engineer, using the principles of hydraulics as a model for the flow of heat (and accordingly the then known inaccurate conservation of caloric principle) wrote his only publication, "Relexions sur la Puissance Matrice de Feu," in which he established the principle that the thermal efficiency of a thermal energy conversion device was maximized when the "flow of heat" was between bodies whose temperatures differ by only an infinitesimal amount.[46] At the time Carnot wrote his article he believed heat to be a fluid, caloric. But

Carnot's views on heat apparently changed before his death in 1832. A few of his undated notes were translated and published in 1878,[47] in which he seems to have adopted the atomists' position. He writes:

> "Heat is simply motive power, or rather motion which has changed form. It is a movement among the particles of bodies. Whenever there is a destruction of motive power, there is at the same time production of heat in quantity exactly proportional to the quantity of motive power destroyed. Reciprocally, whenever there is destruction of heat, there is production of motive power.
>
> "We can then establish the general proposition that motive power is in quantity invariable in nature—that is, correctly speaking, neither ever produced or destroyed. It is true that it changes form—that is, it produces sometimes one sort of motion, sometimes another, but it is never annihilated."

We could be retrospectively generous and conclude from this quote that Carnot was the first to actually state the conservation of energy principle. However, the complete formulation of this principle was not carried out until the second half of the 19th century.

The primitive concepts of metabolic energy balances on physiological systems were apparent in the early experiments of Sanctus Sanctorius (1561–1636).[48] Although his "insensible perspiration" embodied considerably more than simple perspiration, his approach to the balance concept of metabolic energy was unusually advanced. The first to correctly enunciate the conservation of energy principle correctly was a German physician, Julius Robert Mayer.[49] Mayer's interest in energy stemmed from then popular physiological studies on metabolism. As a result he performed no experiments himself but he utilized the results of the experiments of others. This luxury of Mayer's was to cost him most of the credit for the discovery during his lifetime. Mayer published in *Annalen der Chemie und Pharmacie* (1842) his ideas concerning the interconvertability of heat and work. His value for the mechanical equivalent of heat was about 470 Btu/ft lbf.[50]

In 1843, Ludvig August Colding,[51] unaware of Mayer's work, presented a paper to the Danish Academy in which he reported original experiments which established the existence of the proportionality between heat and work. He did not, however, calculate this factor of proportionality.

At about this same time James Prescott Joule was performing extremely well designed experiments to determine the mechanical and electrical heat equivalents.[52] Joule, due to his experimental insight and excellence, received much acclaim for his work. He spent nearly forty years of his life working on various aspects of heat equivalents.

With this single equivalence between work and heat energetics blossomed forth a complete and independent science. In 1848 William Thomson (Lord Kelvin) unearthed Carnot's ideas and developed the absolute temperature scale.[53] Clausius (1850) then removed the conservation of caloric premise from Carnot's formulation and thus established for the first time the complete generality of Carnot's results.[54] Thomson was the first to state both principles of energetics together. In 1851 he wrote:[55]

> "The whole theory of the motive power of heat is founded on the two following propositions, due respectively to Joule and to Carnot and Clausius.
>
> "Prop. I (Joule). When equal quantities of mechanical effect are produced by any means whatever, from purely thermal sources, or lost in purely thermal effects, equal quantities of heat are put out of existence, or are generated.
>
> "Prop. II (Carnot and Clausius). If an engine be such that, when it is worked backwards, the physical and mechanical agencies in every part of its motions are all reversed; it produces as much mechanical effect as can be produced by any thermo-dynamic engine, with the same temperatures of source and refrigerator, from a given quantity of heat."

In 1855 Rankine[56] presented the first complete axiomatic study of the science of energy in his "Outlines of the Science of Energetics." He begins with a detailed discussion of abstractive vs. hypothetical scientific methods, and continues with a series of carefully formulated definitions of such terms as substance, property, mass, work, etc. On page 214 he defines the *Science of Energetics* as:

> ". . . a science whose subjects are, material bodies and physical phenomena in general, . . ."

He then continues, on page 218, with the "First Axiom" of energetics:

> "All Kinds of Work and Energy are Homogenous."

By which he meant that "energy is transformable and transferable."

On page 219 he states the "Second Axiom" of energetics:

> "The Total Energy of a Substance cannot be Altered by the Mutual Actions of Its Parts."

That is *the principle of the conservation of energy.*

And on page 220 he states the "Third Axiom" of energetics:

> "The Effort to Perform Work of a Given Kind, Caused by a Given Quantity of Actual Energy, is the Sum of the Efforts Caused by the Parts of that Quantity."

Unfortunately, Rankine's axiomatic approach did not find favor among his contemporaries. By the beginning of the 20th century the subject was called "thermodynamics," and its governing principles were called "laws." The main influence for this terminology seems to be the writings of Clausius.

Also by the beginning of the 20th century the concept of "heat" had taken on a new meaning. Heat was neither caloric nor was it the motion of atoms. Heat was abstracted, it now represented that energy which is transferred across a system boundary due to a temperature difference.[57] The vibratory motion of the atoms was now regarded as "innerer Arbeit," (interior work) by Clausius;[58] as "intrinsic energy," by Perkins;[59] as "l'energie interne," (internal energy) by Poincaré.[60] Today it is universally known as *internal energy.*

Like *vis viva,* the meaning of the concept of heat cannot be established by an arbitrary definition. Caloric was originally presumed to have weight, but no weight change with caloric change could be measured. However, the modern theory of relativity *predicts* that heat *does* have weight. In 1930 Tolman[61] published "On the Weight of Heat and Thermal Equilibrium in General Relativity," in which he shows that *all* the energy of a system has the property of inertia. Thus if an amount of heat, ΔQ, is added to a system its weight will increase, ΔW, by an amount given by:

$$\Delta W = \Delta Q \left(\frac{g}{C^2} \right),$$

where g is the acceleration due to gravity and C is the velocity of light. Consequently if a body has 1 Btu of energy given to it via a temperature difference between the body and its surroundings, then the weight of the body will increase by about 1.2×10^{-13} lbf (5.5×10^{-11} gm). This value is too small to be detected, even today. But this may not always be the case. What a different history energetics would have had if caloric had been measurable. Thus caloric's last and perhaps greatest success came 150 years too late.

THE INFLUENCE OF MECHANICS

Mechanics has always been the favorite son of science. It became the ruler of architecture—it created the pyramids of Egypt. It became necessary in agriculture—it reaped the Roman wheat. It became useful in commerce—it carried produce to and from foreign ports. Thus human intuition in mechanics has been developed by 10,000 years of the necessity of invention.

In antiquity energy was too abstract a concept to be developed completely; what little energetics there was found itself hopelessly entangled in the mechanics of the day. It was not until the 18th century that energetics began to evolve as an independent entity. But energetics was not looked upon as a welcome addition to mechanics, and by the 19th century, as Gillispie[62] puts it, "energetics became the opposite pole to mechanics." Energetics has not significantly changed its polarity since then. As an axiomatic study it seems to have been stillborn with the work of Rankine. The bastard child—thermodynamics—survived, and as it grew it became evident that it was retarded.

The dynamic aspects of mechanics became more or less axiomatized with the work of Aristotle (ca. 384-322 B.C.). Although he was attempting to emulate nature, he realized this was a formidable task and satisfied himself with principles which were abstract enough so as not to be violated by observations.

Aristotlean dynamics reigned dominant, though inaccurate, for almost 2000 years. It was finally discarded in the 17th century largely as a result of Torricelli's[63] (and others) work with vacuums. The dynamics of Galileo and Newton became firmly entrenched during the 18th century, and today we do not speak of "laws of nature" in dynamics, but instead we speak of Aristotlean, or Galilean, or Newtonian, or Einsteinian dynamics (or rather of the axioms contained in these studies).

The static aspects of mechanics began to become axiomatized with the work of Archimedes (ca. 287-212 B.C.). His entire theory of hydrostatics was founded upon the following two axioms:[64,65]

> "*Postulate 1*
> Let it be supposed that a fluid is of such a character that, its parts lying evenly and being continuous, that part which is thrust the less is driven along by that which is thrust the more; and that each of its parts is thrust by the fluid which is above it in a perpendicular direction if the fluid be sunk in anything and compressed by anything else.
>
> "*Postulate 2*
> Let it be granted that bodies which are forced upwards in a fluid are forced upwards along the perpendicular [to the surface] which passes through their centre of gravity."

Thus, by the 17th century an axiomatic mechanics ruled science. During the 18th century the omnipotent "mechanical philosophy," became deeply entrenched in science. One of the greatest successes of this philosophy was the reduction, at the end of the 19th century, of the concepts of energetics to principles of statistical mechanics, and, in particular, the rendering of Clausius' illusive "entropy" as simply mechanical probability.

The unrealistic zeal of science over the mechanical philosophy essentially smothered the new energetic approach. It emphasized the failure of energetics and at the same time ignored the shortcomings of the theories built on the concept of force. The fall of caloric was a catastrophe, but when the space-filling ether of the mechanists finally dissolved under the influence of Michelson and Einstein,[66] hardly anyone noticed.

It is evident that the influence of mechanics on the philosophies of science was, and is, considerable.

ENERGETICS SINCE RANKINE

Between the work of Rankine in 1855 and that of Carathéodory[67] in 1909 very little contribution was made to the axiomatization of the science energy.

Plank,[68] in his 1897 *Vorlesungen über Thermodynamik,* recogized that there were "essential difficulties . . . in the mechanical interpretation of the fundamental principles of Thermodynamics," and he decided to develop the subject in such a way that:

> ". . . it does not advance the mechanical theory of heat, but, keeping aloof from definite assumptions as to its nature, starts direct from a few very general empirical facts, mainly the two fundamental principles of Thermodynamics."

Although his intentions were good, his approach was not abstract enough to be considered a truly axiomatic study. He could not completely divorce himself from the mechanical world of the cyclic heat engine and perpetual motion.

Rankine axiomatized the conservation of energy principle and, in 1909, Carathéodory, a mathematician, axiomatized the Clausius-Carnot entropy principle. Catathéodory's aim was to establish an equivalent mathematical axiom for the "second law of thermodynamics" which would be independent of any mechanical devices (such as heat engines). He was completely successful, and consequently developed the following statement of the axiom:[69]

> "In the neighborhood of any arbitrary initial state P_o of a physical system there exists neighboring states which are not accessible from P_o along quasistatic adiabatic paths."

In 1917 Tolman[70] introduced today's concepts of "extensive" and "intensive" properties, terms which have been parroted by textbook authors ever since, without bothering to carry along the original meanings. Tolman was attempting to introduce the fundamentals of measure theory into energetics. This problem does not arise in mechanics, since it is built upon our most primitive concepts of measure: mass (and/force), length and time. However, energetics requires, in addition, the measurement of fundamentally more abstract quantities of energy (internal, mechanical, chemical, nuclear, electrical, etc.), temperature, and entropy. Tolman postulated that only *extensive* properties were additive mathematical measures, and thus only they could serve as fundamental quantities. An *intensive* property (such as temperature), therefore, cannot be a fundamental entity.

Fowler and Guggenheim[71] introduced the so-called "zeroth law of thermodynamics" in 1939.[72] It is unfortunate that this terminology has caught on, for this, even more than the other so-called "laws," is no law. Its value to energetics is apparently recognized, but few authors have understood its true meaning. It is nothing more or less than the transitive property (mathematical) which is a necessary condition for the existence of an equivalence relation.[73] If the reflexive and symmetric properties are added to the zeroth law statement,[74] then we have defined "thermal equilibrium" as an equivalence relationship.

More recently the axiomatic approach has been adopted by Landsberg[75,76] (1956), Falk and Jung[77] (1959), Callen[78] (1960), Tiza[79] (1961), Fong[80] (1963), and Truesdell and Coleman[81-83] (1966). Of this group only Landsberg, Truesdell and Coleman are mathematicians, and their developments, as far as they go, are necessarily the clearest. Coleman's work includes the "functional" concept with which Noll[84] had such success in describing material deformation phenomena.

Since Carathéodory energetics has largely been ignored by creative scientists, except for a few, mostly recent, some of whom are mentioned above; nearly all thermodynamics texts written in the last four decades have been written by nut and bolt engineers, men more interested in applications than meanings.

Thomson and Clausius would be puzzled if they read a text of today, for there is hardly a single concept, phrase, or term that was not known to them over a century ago. Have we made no progress in the axiomatization of this subject? I think we have not come far, mainly due to the apathy of a technologically oriented science. But perhaps through a little concerted effort the axiomatization of the statics and dynamics of energetics can be completed, and the subject can be reborn with Rankine's original expectations realized. Then the science of energy along with the science of force can take its rightful place as a part of man's fundamental knowledge.

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THE ORIGIN OF THE WORD "DOLLAR"— THE NAME OF OUR UNIT OF ACCOUNT

Edward E. Popp
Port Washington

In order to conduct business transactions without direct bartering and to be able to record the exchange values of the items and to express and record the exchange values of all goods, currencies, and services, it is necessary to have a unit to serve such purposes. It is necessary to have a common denominator unit which a person can apply to any item in order to express his idea of the exchange value of that item.

Because the unit used to express exchange value is used in accounting, it is called the unit of account. In the United States the word "dollar" is the name of that unit.

The word "dollar" had its origin in Bohemia in 1519 when a Count Schlick, a silversmith, who lived in St. Joachimsthal, Bohemia, made a large silver coin. He gave the coin the name of the village in which he lived, *i.e.,* he called the coin a St. Joachimsthaler. Just as Henry Ford called the automobile which he made a Ford.

Because St. Joachimsthaler was a long name, people began to call the coin a *thaler.* In other German speaking areas it was called a *taler.* Other countries also made a similar coin with a similar name. In Denmark it was called a *daler,* in Holland a *dalder,* in Italy a *tallero,* in Poland a *talar,* and in Spain a *dollar.*

After Spain discovered large deposits of silver in Mexico, it used much of that silver to make silver dollar coins. These coins were used as currency for the vast trade which took place between the Spanish American colonies and the English American colonies. It so happened at that time that the Spanish American colonies had an unfavorable balance of trade with the English American colonies. The result was that a large number of the Spanish silver dollar coins passed into English American hands and circulated as the predominant currency in the English American colonies.

As time passed the English Americans began to express the exchange value, *i.e.,* the price of goods and services in dollars instead of in English pounds, as was their previous custom.

When the exchange values of goods and services were expressed and recorded with the word "dollar" rather than with the word "pound," the word took on an additional meaning. It took on the meaning of the word "pound." The word "dollar" was still used as the name of the large Spanish silver coin, but it also was used as the name of a unit with which to express exchange value.

By the time the English American colonies became independent from England the word "dollar" was so well established in its usage that on July 6, 1785, the United States Congress made the word, dollar, the official name of the unit of account which was to be used in the United States. The Congress called it the official monetary unit, perhaps because the Congress later intended to authorize the minting of a silver coin with the exchange value equal to the value expressed by the dollar unit already in use.

That took place in 1792 when the Congress authorized the mint to make the first silver dollar coins. The price of silver at that time was $1.29 per troy ounce. With the silver at that price it was determined that 371.25 grains of silver had an exchange value of one dollar.

The government declared the coin to be legal tender for a one dollar payment of public and private debts. The coin then had two exchange values:

1. The exchange value of the 371.25 grains of silver.
2. The one dollar legal tender value.

Both values were equal at that time, but they did not remain equal. Between 1794 and 1874 only a small number of silver dollar coins were minted because the exchange value of 371.25 grains of silver was above the legal tender value of the coin.

However, in 1874 large deposits of silver were discovered in Nevada. The result was that the market value of the 371.25 grains of silver in the coin became less than the one dollar legal tender value of the coin. Generally speaking, from 1876 to 1964 the market price of the silver in the silver dollar coin was less than one dollar. At times it was less than fifty cents. With the price of silver today (April 28, 1973) at about $2.25 per ounce the market value of the 371.25 grains of silver may be about $1.75.

We mention these historical facts just to show that the exchange value of the dollar coin is not now and has not been for many years equal to the amount of exchange value expressed by the unit of account called dollar. In other words, the dollar coin and the unit of account called dollar are two different things.

Let us illustrate the point we are trying to make by comparing the dollar unit used to express exchange value, *i.e.*, the unit of account, with a unit we use to express volume. Let us say, the gallon. If a person says that he has a gallon jug, the word "gallon" is used as an adjective. It describes the noun, jug. If a person says that he has a gallon of water, the word "gallon" is used as a noun. It is the name of a unit we use to express a certain volume. A person does not say, I have one gallon, because a gallon as a unit to express volume does not exist as a physical thing. The unit called gallon exists only as a concept.

The same is true for the unit we call a dollar. When the word "dollar" is used as the name of the concept or device we use as a common denominator unit with which we express our idea of the exchange value of goods, currencies, and services, it is used as a noun. When the word "dollar" is used to describe a Federal Reserve note or a coin, it is used as an adjective.

A close study will teach us that the dollar unit of account by itself has no exchange value, because it is not a physical thing. It is a unit concept. It has meaning only when it is applied to something. Just as the word "gallon" has no meaning unless it is applied to something. A person cannot buy a gallon. He cannot carry a gallon. He cannot store a gallon. But a person may buy, carry, or store a gallon of something.

In like manner a person does not receive dollars from a bank. He does not carry dollars in his pockets. He does not store dollars in his safe. But a person may receive, carry, or store dollars' worth of currency (coins or Federal Reserve notes), because items of currency are physical things. They are not concepts.

Also, when we hear the expression, "the dollar lost value," we should know that the statement does not tell us what is meant. We know that the dollar unit did not and could not lose value, because the unit being a concept has no exchange value to lose. What is meant by the expression, "the dollar lost value," is that the currency, the exchange value of which is expressed in dollar units, lost exchange value.

The question might be asked, for what purpose is the dollar unit used? The dollar unit was used and is used to express the ratio of the exchange value of one item with the exchange value of another item. For example, a dollar bill has a specific amount of exchange value, one dollar's worth, when it is used as a payment for taxes. But when it is used to buy goods or services it will have the amount of exchange value to which the buyer and seller mutually agree at the time of each transaction.

As an illustration, let us say, a person offers to sell his potatoes for a one dollar bill per bushel; the one dollar bill will have the exchange value of one bushel of potatoes. If at a later date, he offers to sell his potatoes for two one dollar bills per bushel, each dollar bill will then have the exchange value of only one-half bushel of potatoes. The dollar unit was used to express the two different ratios of the exchange values of the dollar bills and the potatoes.

We should note that the exchange values of both, the dollar bills and the bushel of potatoes, changed from the first transaction to the second transaction. The dollar unit was used to express the different ratios of exchange values of the dollar bills and the bushel of potatoes at both transactions.

When the people in the early days of our country decided to use the amount of the exchange value of the silver dollar coin as the amount of exchange value to be expressed with the dollar unit, the unit expressed the specific amount of exchange value that 371.25 grains of silver had at that time.

The silver dollar coin was intended to be the embodiment of the concept unit called a dollar. It remained so only so long as the price of silver did not increase or decrease. When the price of silver changed the unit called a dollar might just as well have been called a plain unit or a point. Because it served only as an abstract unit with which the exchange value of one item was expressed in its relation with the exchange values of other items.

However, the word "dollar" continued to be used as the name of our unit to express exchange value. So the exchange values of all goods and services are expressed in the ratio of the exchange value of each item with the exchange value of each other item with the abstract unit called a dollar.

Once the ratio of the exchange value of each item is well established in its relation to the exchange values of other items, the exchange values of all items including items of currencies, could be expressed with an abstract unit called a point, just as well as with the unit called a dollar.

In other words, we could say that a bushel of potatoes has the exchange value of one point's worth of the currency and that one point's worth of the currency has the exchange value of one bushel of potatoes. If we did that, then it would be easy to understand that our common denominator unit, that is, our unit of account, is an abstract unit without exchange value in itself.

HISTORY OF BIOLOGICAL CONTROL ATTEMPTS AGAINST INSECTS AND WEEDS IN WISCONSIN

J. W. Mertins and H. C. Coppel
University Wisconsin—Madison

Biological control may be defined generally as the directed use of biotic agents, or their products, for the suppression of living organisms detrimental to man.

The procedure has a long history, dating back to the domestication of the cat for rodent control by the ancient Egyptians. Although sporadic trials and experiments were undertaken in the interim, it was not until 1888 that biological control, as we know it today, was established as a valid method of pest suppression. The importation of the vedalia beetle, *Rodalia cardinalis* (Mulsant), from Australia to California for the control of the cottonycushion scale, *Icerya purchasi* Maskell, a citrus pest, is considered the turning point in our thinking about insect control, and is one of the classical stories in biological control (Doutt, 1964).

The following history of biological control work in Wisconsin, includes attempts against 1 weed and 10 insect pests (listed alphabetically), and several lesser case histories. The resulting overview is a compendium of scattered published accounts and a large body of previously unpublished data from the files of our colleagues.

Cirsium arvense (L.) Scopoli
CANADA THISTLE

The Canada thistle is an introduced noxious weed, naturalized to North America from Eurasia. It was established first in Canada by early 17th century settlers, who probably transported it in contaminated seed (Gilkey, 1957). Shortly thereafter it was discovered in New England, possibly an independent introduction, and has since spread throughout the northern half of the United States and in Canada from Quebec to British Columbia (U.S. Department of Agriculture, 1971). The most serious problems occur in the Lake States, Great Basin, and Pacific Northwest. Worldwide, *C. arvense* is rated as one of the most serious threats to crop production. Efforts toward biological control of this thistle have occurred chiefly in Canada (Peschken, 1971). The most conspicuous natural enemies already occurring there were identified as a leaf bettle, a weevil, a fruit fly, and a rust disease, none of which hold the plant below economic densities. Biological control workers found 80 insect species feeding on *C. arvense* in Europe (Zwölfer, 1965). A leaf beetle, *Altica carduorum* Guérin–Méneville, a weevil, *Ceutorhynchus litura* (F.), and a fruit fly, *Urophora cardui* L., were selected for further study because of their apparent host specificity and climatic suitability. The 2 beetles were subsequently released, but the gall-forming fly is still under study in laboratory culture. Colonies ranging in size from 24 to 1,160 individuals of *A. carduorum* were released in Ontario, British Columbia, Nova Scotia, and Alberta during 1963–1968 (Peschken, 1971). Permanent establishment apparently did not occur, although a small colony survived for 3 years at Lacombe, Alberta, before disappearing. Establishment was probably prevented by heavy predation of the immature stages and excessive adult dispersal. Colonies of 22–150 adult *C. litura* were released at 4 sites near Belleville, Ontario, in 1965 and 1967. It appears that establishment has occurred on only 1 site, a heavily thistle-infested pasture, where 230 beetles were released in 1967.

The release of *A. carduorum* against Canada thistle was the first attempt at biological weed control in Wisconsin (Wisconsin Department of Agriculture, 1968a). Approximately 200 adult beetles were caged for 1 week over a thick patch of thistles in a pasture near Rewey in southwestern Iowa County. The cage was subsequently removed, but periodic recovery attempts in the area have been unsuccessful (Wisconsin Department of Agriculture, 1969), perhaps due to excessive dispersal or unsuitable climate.

Coleophora laricella (Hübner)
LARCH CASEBEARER

The larch casebearer, a European defoliator of larches, occurs throughout the range of its host in eastern North America and in localized infestations in the West. Although about 70 insect parasite species have been reared from *C. laricella* in North America, serious outbreaks and damage were prevalent until the introduction of several European parasites (Sloan, 1965). In eastern North America biological control has progressed to where only minor damage occurs, but western populations apparently still lack effective natural enemies, and heavy defoliation, resulting in radial growth loss, is common.

Biological control of larch casebearer in Wisconsin is one of the most successful of such attempts to date. Casebearers were first recorded from Wisconsin by MacAloney (1939). Wisconsin Conservation Department (now Department of Natural Resources) annual forest insect surveys indicated heavy populations during the period 1951–1956. In the period 1956–1964 populations were reported as "very light to light" statewide, and since 1964, the survey has not reported on *C. laricella*. The reduced importance of *C. laricella* as a pest of larch is traceable in all likelihood to the introduction of 2 species of parasites in August, 1953. A total of 189 male and 158 female *Agathis pumila* (Ratzeburg), a braconid, and 208 male and 235 female *Chyrsocharis laricinellae* (Ratzeburg), a eulophid, were released at 2 sites in northcentral Wisconsin. About half of the total number of each species was released in the Hugo Sauer Nursery near Rhinelander, and the other half in a stand of 35-foot tamarack at the west end of Thunder Lake Swamp, 1 mile west of Three Lakes. These parasites originated from the Dominion Parasite Laboratory, Belleville, Ontario, Canada. A smaller, indeterminate number of parasites originating from casebearer hosts collected in Michigan had also been released at these sites earlier in the season (R. D. Shenefelt, personal communication). Both species became established, and through capture/rerelease and natural dispersal, have spread over the entire state. Sloan (1965) estimated the average annual spread of *A. pumila* after its introduction as equivalent to over 29 miles/year. Within 3 years of the first introductions populations of larch casebearers had dropped to subeconomic levels statewide and have remained essentially so ever since.

Of the two species, *A. pumila* is the most important, accounting for 31–98% of the total parasitization in various localities studied (Sloan and Coppel, 1965). *C. laricinellae* usually accounts for less than 5% of the parasitized hosts. Parasitization resulted in 19–68% host mortality in the various collections studied.

The parasites, *C. laricinellae* and *A. pumila,* were also the subjects of trial exportation from Wisconsin in a cooperative agreement with R. B. Ryan, U.S. Forest Service, Corvallis, Oregon. In June, 1972, laboratory rearings of field collected casebearers produced 45 *C. laricinellae* and 77 *A. pumila* for shipment. The survivors of the insects shipped were to be used for laboratory propagation, and the subsequent progeny released against casebearers in the Pacific Northwest.

Diprion similis (Hartig)
INTRODUCED PINE SAWFLY

The introduced pine sawfly first appeared in North America in a Connecticut nursery in 1914, and probably arrived on ornamental stock imported from Holland (Rowher, 1916). It is now distributed through most of the range of its preferred host, *Pinus strobus* L., in eastcentral North America. The heaviest populations and most serious defoliation occur at present in the Lake States, particularly Wisconsin and Minnesota. Few, if any, parasite importations were made specifically against *D. similis,* but benefits have accrued from releases made against associated sawfly species, and some recolonizations of parasites within the continental area have been directed against this species.

Mertins and Coppel (1971a & b) reported 30 species of insect parasites reared from *D. similis* cocoons in Wisconsin. Five of these account for 94.3% of the parasitization, and all but 1 of the 5 are of European origin. The hymenopterous parasites, *Monodontomerus dentipes* (Dalman), *Dahlbominus fuscipennis* (Zetterstedt), and *Eupelmella vesicularis* (Retzius), were associated with Wisconsin sawfly populations almost from the time of their discovery in 1944, and probably moved into the state with the host. It also appears that these species entered North America accidentally prior to later purposeful introductions. In August, 1953, 3,500 *Diprion* sp. cocoons parasitized by *D. fuscipennis* were obtained from Belleville, Ontario, and set out at 3 widely separated points in Wisconsin by R. D. Shenefelt. Although the parasites were liberated against 3 other sawfly species, it is probable that some individuals attacked *D. similis* cocoons as well. Both *D. fuscipennis* and *M. dentipes* have been reared from field collections of *D. similis* cocoons, and recolonized within the state to areas where they were less abundant. *E. vesicularis,* which frequently functions as a hyperparasite, has not been relocated to new areas. The fourth European species, *Exenterus amictorius* (Panzer), a wasp which attacks *D. similis* in Wisconsin, was originally brought to North America by the Canadian government (McLeod et al., 1962). It has never been released in Wisconsin, but apparently has spread here from release points in southern Ontario. Mertins and Coppel (1968) documented the arrival and increasing abundance of *E. amictorius,* and its relationship with *M. dentipes.* These 2 species account for 87% of the annual mortality caused by parasites and are the most important species present. The suggestion (Mertins and Coppel, 1968) that *E. amictorius* might displace *M. dentipes* as the principal parasite of *D. similis* has now proven itself in fact. *E. amictorius* is now by far the most prevalent parasite reared from cocoons of the first sawfly generation, although *M. dentipes* continues to account for slightly greater mortality in the second (overwintering) generation. At least 11 hymenopterous species have been reared hyperparasitically from *E. amictorius* in Wisconsin (Mertins and Coppel, 1973), and these may possibly reduce the effectiveness of the species below its potential. After establishing the presence of an effective larval parasite *(E. amictorius)* and an effective cocoon parasite *(M. dentipes),* Coppel (1962) and Mertins (1967) suggested introduction of an egg parasite, as well. The European eulophid, *Dipriocampe diprioni* (Ferrière) might be a likely candidate.

The parasites, *E. amictorius* and *M. dentipes,* were also the subjects of exportation from Wisconsin in a cooperative effort with A. T. Drooz, U.S. Forest Service, Research Triangle Park, N.C. In the summer of 1969 adult *E. amictorius* were field collected in Wisconsin and shipped to North Carolina for release; forty-eight parasites were released near Elizabeth City against a pine sawfly, *Neodiprion excitans* Rohwer. Between 1970 and 1972, laboratory rearings of field collected *D. similis* cocoons produced 1,900 *E. amictorius* and 26,350 *M. dentipes* for shipment. The survivors of the insects shipped were released in North Carolina, Virginia, and Florida against the following pine sawflies: *Neodiprion pratti pratti* (Dyar), *N. excitans, N. hetricki* Ross, and *N. lecontei* (Fitch).

Research on the sex pheromone of the introduced pine sawfly as a potential tool for biological control has also centered in Wisconsin (Coppel et al., 1960; Casida et al., 1963; Jones et al., 1965; Mertins, 1971), and work on chemical identification of the substance is progressing (Jewett, 1971). A mathematical model describing the potential effects of pheromone trapping on sawfly populations was devised by Mertins (1971). It predicts the theoretical annihilation of an isolated sawfly population in 3–4 generations of trapping. Experimental traps are under development and a pilot study is planned to test the feasibility of the technique in the field.

Hypera postica (Gyllenhal)
ALFALFA WEEVIL

The alfalfa weevil was probably introduced to the New World from southern Europe about 1900. Injury was first detected near Salt Lake City, Utah, in 1904, and the insect has since spread to most of the alfalfa growing areas in the West. It is also now widely distributed in the East, and is considered the most important insect enemy of alfalfa (Metcalf et al., 1962). Clausen (1956) reviewed the early beneficial insect introductions which began in 1911. Of more than a dozen species introduced, only *Bathyplectis curculionis* (Thomson), an ichneumonid larval parasite, became established in sufficient degree to be effective. It is reportedly found throughout the range of *H. postica* in the West, and in most areas attains a high rate of parasitization, frequently over 90%. With the weevil's invasion of the eastern United States in 1951 came renewed interest in importation of natural enemies, and several additional parasite species were introduced (Brunson and Coles, 1968). In the East, *B. curculionis* again appears to be a significant mortality factor, but other species also contribute additional increments.

The alfalfa weevil was first discovered in Wisconsin in 1966 in Kenosha County. It was considered a severe threat to alfalfa production in the state, which ranks first in the nation in alfalfa acreage (about 3 million acres). Indirectly, the state dairy industry was thus threatened. *B. curculionis* moved into the state along with the host, and was first collected in 1968 emerging from 8% of the weevils collected (Wisconsin Department of Agriculture, 1968b). The abundance of *B. curculionis* varies from area to area, but its distribution generally coincides with that of the weevil, and "it has probably been responsible for slowing the increase of alfalfa weevil populations in Wisconsin" (Wisconsin Department of Agriculture, 1971b). Parasitization reached 62% in some fields in the southern tier of counties in 1971, where the highest weevil populations have been found. Despite the presence of the parasite, alfalfa weevil now occurs in all except the 13 northernmost counties of the state.

In supplement to the naturally occurring *B. curculionis*, J. W. Apple and J. A. Litsinger released 691 additional parasites in Kenosha and Rock Counties in 1969 and 1970. The parasites were provided by the U.S. Department of Agriculture, Moorestown, N.J., which, along with personnel at Wooster, Ohio, also provided 6 other hymenopterous species for release against the weevil in Wisconsin: 2,578 *Microctonus aethiops* (Nees) in Kenosha, Rock, Dane and Sauk Counties, 1969–1972; 41 *M. colesi* Drea in Kenosha County, 1969; 190 *M. stelleri* Loan in Rock County, 1970; 1,603 *Tetrastichus incertus* (Ratzeburg) in Kenosha and Columbia Counties, 1967 and 1972, respectively; 1,256 *Bathyplectes anurus* (Thomson) in Kenosha, Rock, and Dane Counties, 1969–1971; and 431 *B. stenostigma* (Thomson) in Kenosha and Rock Counties, 1969–1970. Despite these releases, the only parasite known to be established on the alfalfa weevil in Wisconsin is *B. curculionis*. Recently a secondary ichneumonid parasite, *Gelis* sp., has been reared in very small numbers from Wisconsin *B. curculionis*. At present it is of little consequence, but its occurrence bears watching because of potential detrimental effects it may have on the primary parasite population. Mortality to *B. curculionis* eggs through host encapsulation has occurred in the western states, but it has not been found in Wisconsin to date.

Neodiprion lecontei (Fitch)
REDHEADED PINE SAWFLY

The redheaded pine sawfly is one of the most important native forest insects defoliating young hard pines in eastern North America (Benjamin, 1955). During the 19th century the insect was only of minor significance on park and shade trees, but with the advent of extensive pure pine plantations in recent years, many local and widespread outbreaks have occurred. The sawfly has been recorded from nearly every state east of the Mississippi River, adjacent Canada, and the 5 states adjacent to the Mississippi on the west. Benjamin (1955) listed 58 species of parasitic and predatory insects known to be associated with *N. lecontei* in eastern North America, but remarked on the lack of emphasis on employing biological agents in population management of this sawfly. Releases of only 2 parasite species have been directed against *N. lecontei* in the United States (Dowden, 1962). In 1932, 120 *Drino bohemica* Mesnil (Diptera: Tachinidae) were liberated in Pennsylvania; no recoveries were made. From 1940 to 1946 more than 1.3 million *Dahlbominus fuscipennis* were released in Alabama, Tennessee, New York, and Michigan. Few recovery attempts were made, but *D. fuscipennis* was established on *N. lecontei* in Lower Michigan.

To our knowledge, the only biological control attempt against *N. lecontei* in Wisconsin took place in August, 1953, when 2,600 sawfly cocoons parasitized by *D. fuscipennis* were set out against it (and the larch sawfly, *Pristiphora erichsonii*) in Burnett County just west of McKenzie Lake. Labeled specimens in the U.W. Insectarium confirm that *D. fuscipennis* is established on the redheaded pine sawfly in Wisconsin.

Neodiprion sertifer (Geoffroy)
EUROPEAN PINE SAWFLY

The European pine sawfly was first discovered in New Jersey in 1925. Currently its range extends through scattered infestations in most all the states between New Jersey and Maine on the east and Iowa and Missouri on the west, including the southeastern portion of Ontario as well. The Canadian government has released large numbers of parasites against the sawfly, and also developed the use of an effective polyhedral virus disease introduced from Europe. Colonies of the parasites as well as the virus were obtained from Canada and released in the United States, particularly in New Jersey where severe defoliation was observed (Dowden, 1962). Of 7 species liberated, 3 Hymenoptera are established: *Dahlbominus fuscipennis, Exenterus abruptorius* (Thunberg), and *Pleolophus basizonus* (Gravenhorst).

The nature of the first recorded appearance of *N. sertifer* in Wisconsin is shrouded in uncertainty (D. M. Benjamin, personal communication). A single larva determined as this species by several authorities was discovered amongst a group of *Neodiprion nanulus* Schedl larvae collected near Arkdale (Wood County) in

1955. No other specimens were found at that time or later, but to offset the potential threat of infestation, approximately 23,000 *D. fuscipennis* were released, the area was treated with a quantity of the polyhedral virus obtained from the U.S. Forest Service in Columbus, Ohio, and sprayed with DDT. It is probable that the parasite release was useful, insofar as *D. fuscipennis* was established on *N. nanulus*. In the spring of 1972 a verified infestation on *N. sertifer* was discovered in southern Walworth County, and parasite or virus releases are contemplated for 1973.

Neodiprion swainei Middleton
SWAINE JACK PINE SAWFLY

The Swaine jack pine sawfly has been one of the most important pine-infesting sawflies in eastern Canada for many years. It was first noted in the Lake States in the early fifties, and is now widely distributed in Upper Michigan, northcentral Minnesota, and Wisconsin. The Canadian government released 2 parasites, the ichneumonid, *Pleolophus basizonus,* and the tachinid, *Drino bohemica,* against *N. swainei,* and both have been recovered (McLeod and Smirnoff, 1971). Two other species, *Exenterus amictorius* and *Dahlbominus fuscipennis,* released against the European spruce sawfly, *Diprion hercyniae* (Hartig), have also been recovered from *N. swainei.* None of these parasites occur in large numbers. Smirnoff (1967) described the use of a polyhedral virus in extensive field tests in Canada. The virus was very effective and persisted in the population for several years.

The sawfly has occurred in outbreak conditions in southwestern Wisconsin, and one parasite release against it was made by R. D. Shenefelt in August, 1953. Six-hundred sawfly cocoons parasitized by *D. fuscipennis* were set out in an infested jack pine stand 1 mile west of Arena in Iowa County. The parasite became established, but before its effectiveness was determined the sawfly population collapsed.

Ostrinia nubilalis (Hübner)
EUROPEAN CORN BORER

The European corn borer was probably introduced accidentally to North America about 1909 in broomcorn shipped from Italy or Hungary (Metcalf et al., 1962). Since the time of its first detection near Boston, Massachusetts, in 1917 it has become one of the most destructive insect pests of corn. The present distribution of the corn borer covers practically all the major corn-growing areas of the United States, including all of the states north of Florida, Louisiana and Oklahoma, and east of Montana, Wyoming and Colorado. Parasite importation investigations were begun almost immediately by the U.S. government, and between 1920 and 1938 approximately 3 million individual parasites were imported from Europe and the Orient, representing 24 species of Diptera and Hymenoptera. Although 6 or 7 of these species became permanently established in the Northeast where they were released, only 2, the tachinid, *Lydella thompsoni* Herting, and the braconid, *Macrocentrus grandii* Goidanich, became sufficiently abundant or widely distributed to be of appreciable value (Clausen, 1956). *M. grandii* is the dominant species in New England where parasitization up to 52% has been observed, and *L. thompsoni* has accounted for mortalities of 10–45% in the East and 45–75% in the northcentral states.

As the borer continued to spread westward across the corn belt during the 1930's and 1940's, entomologists continued to move its parasites into the new areas as well. The insect was first discovered in Wisconsin near Sheboygan in 1931, and beginning in 1942 parasites provided by the U.S. Department of Agriculture were released in the state by the Wisconsin Department of Agriculture and the University of Wisconsin, Department of Entomology. The first year about 3,300 individuals were released, over half of which were *M. grandii.* During the 8 year period 1942–50, over 109,800 parasites of 5 different species were imported from the Northeast and released in Wisconsin against the borer (Wisconsin Department of Agriculture, 1971a). More than 80% of these were *M. grandii,* but also included were *L. thompsoni,* and the hymenopterans, *Horogenes punctorius* (Roman), *Sympiesis viridula* (Thomson), and *Chelonus annulipes* Wesmael. Recoveries were subsequently made of all 5 parasite species, but *C. annulipes* apparently did not become permanently established. The dipteran, *L. thompsoni,* for several years occurred in large numbers, reaching a peak parasitization rate of 42% in 1950, and a lesser peak of 20% in 1958. However, by 1964 it had disappeared from fall corn borer surveys in Wisconsin as well as in other midwestern states, and it has not been recovered in significant numbers since. The status of *S. viridula* is currently unsure because it is usually not encountered in survey work due to its host selection habits. It is believed to occur in low numbers. *H. punctorius* and *M. grandii* are currently the most frequently encountered introduced parasites in Wisconsin, accounting for parasitization of 2–5% between them on a statewide basis. Parasitization is highest in the southwest area where it generally reaches 12–15%. It is also interesting to note that *M. grandii* was not recovered in significant numbers on a consistent basis until 1959, 9 years after it was last released in the state (J. W. Apple, unpublished data).

Although the introduced parasites established in Wisconsin on the European corn borer do not account for a great deal of mortality, they add to that caused by several of the 30 species of recorded native parasites. The most important of these in Wisconsin are the tachinid flies, *Aplomya caesar* (Aldrich) and *Pyraustomyia penitalis* (Coquillett). Other natural mortality factors aiding in reduction of corn borer populations and infestations are a protozoan disease organism, *Perezia pyraustae* Paillot, and numerous predators including coccinellids, chrysopids, nitidulids, and a number of birds, especially the woodpeckers (Baker et al., 1949).

Pristiphora erichsonii (Hartig)
LARCH SAWFLY

The larch sawfly is apparently a true Holarctic species as its range follows most of the circumpolar distribution of its host trees in the genus *Larix*. However, the insect was not reported in North America before 1880 when it was discovered in Massachusetts (Drooz, 1960), and the nature of its distribution before that time is unsure. Many widespread and serious outbreaks have occurred since 1880 covering virtually all of the Canadian provinces and the northern tier of states where larches grow. The highly successful ichneumonid parasite, *Mesoleius tenthredinis* Morley, against the larch sawfly was introduced to Canada from England in 1910–11. By 1950, parasitization rates of up to 90% were recorded and average rates were 55–75%. A few small releases of *M. tenthredinis* were made in the U.S. in Michigan, Minnesota, New Hampshire, and Massachusetts, but it is unlikely that they affected the spread of the parasite (Dowden, 1962). However, *M. tenthredinis* has spread effectively into the Lake States and New England from Canadian releases (Drooz, 1960). Unfortunately, the importance of *M. tenthredinis* has decreased greatly in central Canada and the Lake States; an immune reaction has been developed by the host against the parasite egg, resulting in encapsulation and prevention of development.

The natural spread of *M. tenthredinis* into Wisconsin resulted in reported parasitization levels of about 40% by 1935 (Drooz, 1960), but by 1954 the rate of effective parasite attack was reduced to 3% or less by encapsulation. The only active biological control attempt against larch sawfly in Wisconsin was carried out by R. D. Shenefelt in August, 1953. Sawfly cocoons parasitized by *Dahlbominus fuscipennis* were obtained from Canada and set out in two areas: about 2,600 cocoons 1 mile north of Solon Springs in Douglas County, and about the same number in Burnett County just west of McKenzie Lake, in an area also infested by *Neodiprion lecontei*.

Scolytus multistriatus (Marsham)

SMALLER EUROPEAN ELM BARK BEETLE

The smaller European elm bark beetle is an introduced pest of elms first observed near Boston, Massachusetts in 1909 (Baker, 1972). Were it not for the fact that it is the major vector of the Dutch elm disease fungus, *Ceratocystis ulmi* (Buisman) C. Moreau, the beetle would be of little concern, for it usually breeds only in weakened or unhealthy trees. However, the beetle-fungus association has spread over most of the United States and southern Canada. The disease is also present in areas beyond the distribution of the introduced vector where it is transmitted by a native elm bark beetle. Six parasite species were known from *S. multistriatus* in North America before any importations were attempted (Bushing, 1965). Although insufficient in numbers to control the beetle, 3 of the species are fairly common, and 2 of these, *Cheiropachus colon* (L.) and *Entedon leucogramma* (Ratzeburg), are European hymenopterous parasites established in the United States at an early date by unknown means (Kennedy, 1970). In September, 1964, the first shipment of a braconid parasite, *Dendrosoter protuberans* (Nees), was received from France by the U.S.D.A. Laboratory colonies were maintained at Michigan State University, East Lansing, and the Northeastern Forest Experiment Station, Delaware, Ohio, and in 1966 releases were made on field plots in Ohio and Missouri; the parasite was apparently successfully established (Kennedy, 1970), and a small population is also established in Detroit, Michigan (Kennedy, personal communication).

The first recorded occurrence of *S. multistriatus* in Wisconsin was in 1952 (Wisconsin Department of Agriculture, 1956), but it had probably been present for several years. Dutch elm disease was not found until 1956. The previously mentioned common parasite species have also been found, but have not adequately controlled bark beetle populations in Wisconsin. Consequently, in July, 1967, Milwaukee County Forestry Department personnel in cooperation with U.S.D.A. entomologist B. H. Kennedy released a total of 248 male and 609 female *D. protuberans* on 5 beetle-infested parkland trees. Samples taken from 3 of the trees in August, 1967, indicated initial establishment of the parasite with a recovered:released ratio of nearly 1:1 (Kennedy, personal communication). However, the following year a stream channelization project almost completely destroyed the release area, and samples from 2 of the small trees remaining failed to produce *D. protuberans* (Kennedy, personal communication). It is not known if the parasite established itself beyond the initial release site.

Synanthedon pictipes (Grote and Robinson)
LESSER PEACH TREE BORER

The lesser peach tree borer is a native insect pest of peach, cherry, and plum trees. Although most common in the South, it ranges from southern Canada to the Gulf of Mexico, and from the Great Plains east to the Atlantic coast (Gilbertson, 1934). Branch and tree mortality frequently occurs when large larval populations girdle the affected parts. Several native parasites, a fungal disease, and various insect and bird predators account for some natural mortality, but borer populations are seldom held in check by these agents because of their well protected habitat (King, 1917).

Although peaches and plums are not raised commercially in Wisconsin, sour cherries are a major orchard crop in the state, and *S. pictipes* may well be the most important pest of cherry in commercial plantings (Koval, personal communication). In 1969 personnel of the U.S.D.A. Deciduous Fruit Insect Investigations Laboratory at Vincennes, Indiana, began initial surveys on Washington Island, Door County, Wisconsin, to determine the feasibility of suppressing borer populations with a sex pheromone trapping program (Wong et al., 1971). Extensive field work was begun in 1970 in cooperation with C. F. Koval and M. G. Karandinos, Department of Entomology, University of Wisconsin, and by 1972 a trapline of about 3,000 virgin female-baited traps was in operation continuously during the flight season. After the 1972 trapping program it was estimated that a population reduction of 42% had been attained (Koval, personal communication). Plans call for continuation of these studies, and details are being worked out for the addition of a proposed concurrent sterile male release program.

Several other programs are in progress or under consideration utilizing the unique advantages of Washington Island's relatively isolated insect populations. In 1971, a trapline of 18,000 traps was maintained by U.S.D.A. personnel to test and compare effectiveness of synthetic pheromones and virgin females of the codling moth, *Laspeyresia pomonella* (L.). Additional similar investigations involved the redbanded leafroller, *Argyrotaenia velutinana* (Walker), and a sterile male release program against the horn fly, *Haematobia irritans* (L.), is scheduled for 1973.

MISCELLANEOUS EFFORTS

In addition to the preceding documented case histories, a number of minor or little known efforts and suggestions for biological control have been made in Wisconsin. A few of these have come to our attention and are included.

In 1971, C. F. Koval of the Department of Entomology reared a number of specimens of the eulophid parasite, *Encarsia formosa* Gahan, from greenhouse whiteflies, *Trialeurodes vaporariorum* (Westwood), collected in a University of Wisconsin greenhouse. This was the first record of the parasite in Wisconsin, and its activities in the greenhouse continue to be monitored. Although *T. vaporariorum* does not survive Wisconsin winters outside, it does build up large populations during the summer months in ornamental and floral gardens replanted each year from greenhouse stock. Therefore, an undetermined number of *E. formosa* were recolonized from the greenhouse to a horticultural garden on campus where the whitefly was a problem. Recovery collections made later in the summer showed establishment of the parasite at a parasitization rate of about 25–30%.

A number of studies have been carried out in Wisconsin on the use of microbial pathogens for insect control, with varying results. Walgenbach and Benjamin (1965) field tested the bacterium *Bacillus thuringiensis* Berliner (Thuricide® 90T) for suppression of pine tussock moth larvae, *Dasychira plagiata* (Walker), on jack pine. The treatment caused no significant reduction in numbers of 5th-6th instar larvae against which it was applied. In at least one instance, however, practical recommendations providing for the use of such materials on a commercial basis have resulted (Libby and Wade, 1971). Certain commercially available preparations of *B. thuringiensis* var. *alesti* successfully suppressed populations of cabbage caterpillars, including *Pieris rapae* (L.), *Plutella xylostella* (L.), and *Trichoplusia ni* (Hübner), under Wisconsin conditions (Libby and Chapman, 1971). J. W. Apple (personal communication) found that 4 applications of Dipel®, a commercial preparation of *B. thuringiensis*, provided 80% protection of sweet corn from European corn borer in Wisconsin, compared to 97% protection with the recommended treatment of 4 applications of Sevin® insecticide.

Finally, we must include mention of the many dedicated amateur naturalists, organic gardeners, and other concerned citizens who have attempted to reduce their use of pesticides around the home garden and farm by releasing unknown numbers and kinds of insect parasites and predators obtained from any of at least 20 commercial insectary sources. For example, records of only one such company, Rincon–Vitova Insectaries, Inc. of Rialto, California, indicate shipment of the following insects to Wisconsin during the last 5 years: 58,000 eggs of the green lacewing, *Chrysopa carnea* Stephens; 528,000 *Trichogramma* spp. egg parasites; 25,000 hymenopterous parasites including *Tachinaephagus zealandicus* Ashmead, *Spalangia endius* Walker, and *Muscidifurax raptor*

Girault and Sanders for pestiferous flies; 200 of the lady beetle, *Cryptolaemus montrouzieri* Mulsant; and 200 convergent lady beetles, *Hippodamia convergens* Guérin–Méneville (L. Wainscott, personal communication). One other organization reports shipping coccinellids to Wisconsin, and a third company sent *Trichogramma* to more than 25 customers in recent years. Also, the Chinese mantis, *Tenodera aridifolia sinensis* Saussure, has been introduced into several areas of the state, although the status of its establishment is unsure. At least 4 organizations responding to our questionnaire have sold mantis oothecae to Wisconsin customers. One or 2 specimens of this mantis are submitted by local citizens to the Milwaukee Public Museum nearly every year (K. MacArthur, personal communication); an ootheca containing infertile eggs was collected in 1967 by one of the authors (J.W.M.) from a weedy area of the University of Wisconsin Arboretum in Madison; and the progeny from about 15 oothecae were released in a vegetable garden in Amery, Wisconsin in 1971.

SUMMARY DISCUSSION

It is evident from the information presented that the utilization of applied biological control in Wisconsin is as yet relatively meager. None of the case histories described involved an extensive program including recognition of the problem, investigation of the pest and its ecology, biological and ecological studies of the beneficial organism(s), collection, importation and mass rearing of the biotic agent(s), field releases, and follow-up recovery studies to determine establishment and spread of introduced biotic agents. That is not to say that the biological control approach cannot be followed without involved ecological investigations and methodology. Simmonds (1972) recently discussed this problem thoroughly, alluding to the practical, temporal, and economic considerations involved, and concluded it is better to make a few expedient introductions which *may* be of value than to do nothing at all. A case in point is the biological control of the larch casebearer in Wisconsin, the most successful introduction program on record in the state. Although the program was not conducted on a grand scale, with great financial outlay or exhaustive investigations, the results were significant. The non-classical approach used in the lesser peach tree borer trapping program on Washington Island makes it difficult to compare with the other classical programs discussed, but, in its own way, this study will probably result in an exhaustive set of data relating to objectives, procedures, and results.

The complete ecologically based program is by far the preferred approach when it is feasible. For a number of years the forest entomology research group (D. M. Benjamin, H. C. Coppel, D. M. Norris, R. D. Shenefelt) of the Department of Entomology has conducted basic studies on the ecology and natural control factors affecting forest insect pests in Wisconsin, thus providing a sound basis upon which future biological control programs can be planned. Information has accumulated on *Acrobasis rubrifasciella* Packard, *Choristoneura fumiferana* (Clemens), *C. pinus* Freeman, *Dasineura balsamicola* (Lintner), *Dasychira plagiata* (Walker), *Dendrotettix quercus* Packard, *Glyptoscelis pubescens* (F.), *Hylobius* spp., *Pissodes strobi* (Peck), *Reticulitermes flavipes* (Kollar), *Rhyacionia buoliana* (Schiffermüller), *Toumeyella numismaticum* (Pettit and McDaniel), and others.

The classical biological method of pest suppression has practical and desirable advantages for many pest species. First, it is often self-sustaining. Once effective introduced beneficial agents have been established, no further efforts or expenditures may be required to avoid economic losses caused by the pests. In other cases, periodic (early in the season or generation every year) or inundative (much in the manner of an insecticide) releases of beneficial agents may be necessary to restrain pest populations. Secondly, the self-sustaining nature of an effective biotic agent may alleviate the necessity for routine periodic chemical applications with their associated problems of residues, pest resistance, broad spectrum toxicity, and environmental contamination. In conjunction with these advantages are certain problems which in some instances must be given consideration. Chemical pest suppression usually gives quick and highly visible pest relief. Biological control requires a certain lag time until the biotic agent establishes its effectiveness, and although it is present and active, it is not always readily observable to the untrained eye. This fact is exemplified by a consideration of the thousands of insect species which share the environment with man, but are not economic pests. Natural enemies of these potential pests are omnipresent and keep their numbers in check, frequently without receiving due credit. Even though a pest species population has been successfully reduced to tolerable or subeconomic levels by an introduced biotic agent, pest numbers are still subject to fluctuation from year to year. Complete population control is rarely obtained. Instead a desirable balance is sought between detrimental and beneficial species numbers. In some high value crops, such as fruits and vegetables, consumer demand for virtually unblemished produce will not allow even an occasional high insect population to occur, and in these instances the grower may have to resort to alternative methods of suppression.

Although chemical and biological controls are sometimes in direct opposition, they are not always mutually exclusive. The coordinated use of the two methods at the same time, or for that matter, the harmonious use of *any* two or more pest suppressive methods may be termed integrated control, or integrated pest management, and currently such systems are receiving increased attention (National Research Council, 1969; Northeastern Forest Experiment Station, 1971). Research along these lines is also underway in Wisconsin, and a number of reports have appeared (Coppel and Norris, 1960; Oatman, 1966; Eckenrode, 1970).

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NUTRIENT SOURCES FOR LAKE MENDOTA—1972

William C. Sonzogni
University Wisconsin—Madison
and
G. Fred Lee
University Texas—Dallas

INTRODUCTION

It has been several years since Lee *et al.* (1966) published an estimation of nutrient loadings to Lake Mendota (the paper was revised in 1969, but only with regard to the figure for the annual nutrient input from nitrogen fixation). Since that time new data and information concerning certain nutrient sources has become available. In addition, changes in the population and land use of the watershed have occurred. In view of the recent diversion of sewage effluent which normally entered tributaries to the lake, it is imperative that the sources, amounts and types of nutrients be estimated as well as possible, if the effect of this diversion is to be properly evaluated. It is the purpose of this paper to update the estimation of the total amounts of nutrients entering Lake Mendota as well as to provide some quantitative information on the forms of nutrients annually entering the lake from different sources.

LAKE CHARACTERISTICS

Lake Mendota, perhaps the most studied lake in the world, is the largest of the Madison lakes, which form a chain along the Yahara River. Formed as a result of moranic damming during the most recent ice age, it is classified as a hard-water, eutrophic lake according to most standards. The drainage area of Lake Mendota is composed mostly of fertile farm land and urban area. The hypolimnetic waters become devoid of oxygen during summer stratification and during late winter oxygen depletion occurs in the bottom water. Excessive weed growth and periodic algal blooms create offensive conditions during the summer months.

The lake is located in south-central Wisconsin, which has a semi-humid climate. The monthly average temperatures range between 19 F and 73 F (Dane County Planning Commission, 1971). Precipitation averages about 30 inches each year, while evaporation amounts to about 24 inches a year.

Lake Mendota has a volume of about 128 x 10^9 gal. (486 x 10^6 m^3) and a surface area of about 9,700 acres (3940 ha.). The maximum depth of the lake is 84 ft (25 m), while the mean depth is about 40 ft (12 m). The tributary flow into the lake is on the order of 100 cfs (Burgy, 1950; Cleasby, 1951), the highest monthly inflows being recorded during spring thaw. A synopsis of limnological information on the lake may be found in Frey (1963).

Land Use

Land usage within the Mendota basin was estimated from maps and current land use information provided by the Dane County Planning Department. All incorporated land area within the watershed was considered to be urban. The remaining land was categorized as rural, marshland, or woodland, except for land designated as residential or land used for transportation, utility or communication purposes. Such land was counted as urban drainage. Marshland and woodland were estimated from a map prepared by the Planning Department.

Table 1 compares the land use estimates of Lee *et al.* (1966) with those of this study. The only significant difference is with urban area and woodland. The increased urban drainage area may be the result of recent urban sprawl. The decreased woodland area in the revised estimate is probably due to the fact that only the major woodland areas were counted in the study. Small clumps of woodland of only a few acres could not be differentiated from rural land.

ESTIMATED NUTRIENT SOURCES

Base Flow

Estimates of the nutrient contribution from base flow (portion of total tributary flow which is derived from ground water) are summarized in Table 2. It can be seen that the few studies that

TABLE 1. PREVIOUSLY PUBLISHED AND REVISED ESTIMATE OF LAND USE WITHIN THE LAKE MENDOTA WATERSHED

	Lee *et al.* (1966)		Revised	
Land Use	Acres	%	Acres	%
Rural	114,000	81	115,000	83
Urban	11,000	7	16,000	12
Marshland	7,000	5	6,000	4
Woodland	10,000	7	1,000	1
Total	142,000	100	138,000	100

TABLE 2. BASE FLOW

Source	Soluble Ortho—P	Total P	NH_4^+—N	NO_3^-—N	Org—N	Total N
			lbs/acre/year			
Minshall *et al.* (1969)	----	0.1	----	----	----	1.1
Comment: Southwestern Wisconsin streams; includes minor waste discharge						
Zitter (1969)	0.13	0.17	0.27	0.65	1.0	1.9
Comment: Six Mile Creek-South (a Mendota tributary)						
Gardner (1971)	0.06	0.15	----	1.13[1]	0.22	1.35
Comment: Includes some waste water discharge. Based on data of Belter and Calabresa (1950)						

[1]Inorganic nitrogen

have been made are in surprisingly good agreement despite the different ways in which the estimates were obtained and the different study areas. When examining Table 2 (and future tables) it should be noted that one lb/acre is approximately equal to one kg/ha.

Minshall *et al.* (1969) estimated the quantity of nutrients carried by base flow annually during a two-year study of streams in southwestern Wisconsin. Lake Mendota tributaries were deemed unsuitable for determining base flow on account of possible pollution from domestic and industrial sources. For this reason, the authors decided to study base flow in southwestern Wisconsin, a predominately rural area whose streams receive little such pollution. Minshall *et al.* (1969) felt that the nutrients carried by base flow in these streams would be roughly comparable to the nutrients transported by base flow in the Madison area.

Minshall *et al.* (1969) reported that the average annual base flow in the drainage areas of southwestern Wisconsin was 0.360 cfs/mi.^{2} Cleasby (1951) and Burgy (1950) found the inflow to Lake Mendota to be approximately 95 cfs per year. If one takes the watershed of Lake Mendota to be about 250 mi,^{2} then the average base flow is 0.38 cfs/mi.^{2} This suggests a comparable base flow rate on a unit area basis. Minshall *et al.* (1969) also found that the annual nutrient input from base flow per acre of drainage was generally constant for the different streams studied and variations appeared independent of flow. Thus, the results of Minshall *et al.* (1969) are quite likely applicable to Lake Mendota.

Zitter (1969) studied a portion of the watershed of Six Mile Creek-South, a tributary to Lake Mendota. The drainage area is predominantly agricultural (dairy farms and mixed crops). Using automatic sampling equipment and continuous flow measuring devices, the annual nutrient contribution from the watershed due to base flow and surface runoff was estimated. Although Zitter's data did not explicitly separate base flow from surface runoff, he observed that about 75% of the annual nutrient losses occurred during periods of high runoff, suggesting that base flow accounted for about 25% of the nutrients carried by the stream.

Gardner (1971) attempted to separate base flow from total runoff from the tributary nutrient input data for Lake Mendota, compiled by Belter and Calabresa (1950). Gardner (1971) summed cumulatively the nutrient quantities (soluble ortho-P, total-P, organic-N, inorganic-N) from all the tributary sources and plotted them versus time. He then used the rate changes to roughly differentiate between base flow and runoff during the four seasonal periods. During periods when no runoff was thought to have occurred, the rate of nutrient input was relatively constant and significantly lower than during periods when runoff was known to occur. From these periods of low, constant input an assessment of the base flow nutrient contribution was made. The results included any municipal and industrial wastes discharged into the tributaries.

Since the data for base flow in Table 2 implicitly includes small but significant nutrient contributions from other sources (i.e., small waste water inputs, barnyard drainage, septic tank seepage and others) which are difficult to separate from the nutrients in stream flow arising solely from ground water flow, the values listed in Table 2 may overestimate the base flow input. For this reason, the values reported by Minshall *et al.* (1969), which were the minimum values reported in Table 2, will be used to reestimate the nutrient loadings from base flow. The forms of nutrients in base flow would be expected to be predominantly NO_3^-—N and soluble ortho-P.

If a tributary drainage area of 123,000 acres (Belter and Calabresa, 1950) is assumed for Lake Mendota, an average annual loading of 12,000 lbs of phosphorus and 135,000 lbs of nitrogen can be predicted, using the data of Minshall *et al.* (1969). The previous estimated contribution of base flow, based on the amount of ground water thought to be entering the tributaries directly (see section on *Ground Water Seepage*), was 79,000 lbs/year of nitrogen. No estimate of the phosphorus input from base flow was made in the previous study. Thus, in the case of nitrogen the new estimate about doubles the old one.

An important point to consider is the denitrification of ground water as it emanates from marshy areas and contributes to the base flow of streams. Lee *et al.* (1971) found significant denitrification reactions, which result in the conversion of nitrate nitrogen to nitrogen gas, occurring in the Mendota watershed. It is also possible that the opposite reaction, nitrogen fixation, could occur within a marsh (a study is currently underway at the University of Wisconsin Water Chemistry Program to determine the significance of nitrogen fixation in the marsh environment). These reactions would have to be accounted for if the nitrogen contributed by base flow were estimated from the amount of ground water entering tributaries directly, as was done in the Lee *et al.* (1966) report.

Rural Runoff

Several studies have been conducted in the Madison area which have estimated the average annual nutrient loading from rural or agricultural runoff. The results of these studies have been summarized in Table 3.

Witzel *et al.* (1969) measured the amount of surface runoff from several agricultural watersheds near Fennimore, Wisconsin, in 1967. Based on the data obtained they found the contribution of surface runoff to be 3.6 lbs of total-N/acre/year and 1.1 lbs of total-P/acre/year. However, because the 1967 winter runoff in the area was about twice normal because of one heavy rain in January, they estimated the nutrient losses for a typical year to be only 2 lbs of total-N/acre/year and 0.61 lbs of total-P/acre/year, assuming that nutrient losses were directly proportional to runoff.

TABLE 3. NUTRIENT LOADING FROM RURAL RUNOFF—ESTIMATES FOR SOUTHERN WISCONSIN AREA

Source	Soluble Ortho—P	Total P	NH_4^+—N	NO_3^-—N	Org—N	Inorg—N	Total N
				lbs/acre/year			
Witzel *et al.* (1969)	----	0.6	----	----	----	----	2.0
Comment: Estimated for normal year—Southwestern Wisconsin							
Witzel *et al.* (1969)	----	1.1	----	----	----	----	3.6
Comment: Measured during study							
Zitter (1969)	0.39	0.53	0.85	1.50	3.19	2.35	5.66
Comment: Measured runoff—Mendota tributary							
Zitter (1969)	0.60	0.80	1.3	2.3	4.8	3.6	8.6
Comment: Estimated for normal year							
Gardner (1971)	0.08	0.15	----	----	0.47	0.94	1.41
Comment: Based on Belter and Calabresa (1950)							
Sawyer (1947)	0.08	0.40	----	----	1.75	5.2	7.0
Comment: Uncorrected for base flow							
Sawyer (1947)	----	0.30	----	----	----	4.1[1]	5.9
Comment: Corrected for base flow estimated by Minshall *et al.* (1969)							
Average[2]	0.3[3]	0.6	----	----	1.8[4]	2.8	4.5

[1] Correction made assuming base flow all inorganic N
[2] Averages computed from Sawyer's values corrected for base flow
[3] Assume soluble ortho—P equals 50 % of average total—P
[4] Difference between average total—N and average inorganic—N

Zitter (1969) studied a portion of the watershed of Six Mile Creek-South. As mentioned previously, surface runoff and base flow were not measured separately, but about 75% of the annual nutrient losses occurred during periods of high flow and thus was considered to be the result of surface runoff. Zitter (1969) reasoned that his data probably underestimated the normal nutrient contribution of the watershed due to the below normal winter precipitation the year of his study. Because of the lack of snow, manure was spread on bare ground or on a very thin layer of snow. Consequently, Zitter (1969) concluded that there probably was not sufficient water at spring thaw to leach all the nutrients from the manure and carry them into the stream. Zitter (1969) therefore multiplied his runoff results by 1.5, as he felt the resulting figure would be more representative of nutrient losses during a normal year.

Sawyer (1947), during a study of the Madison lakes in the mid-1940's, determined the nutrients in the agricultural drainage to Lakes Monona, Waubesa and Kegonsa. The data shown in Table 3 represent the average for the three lakes studied. No attempt was made to differentiate between base flow and runoff. Sawyer's results minus base flow (as estimated in the previous section) are also included in Table 3.

As discussed previously, Gardner (1971) used the data of Belter and Calabresa (1950) to separate base flow and rural runoff from total nutrient input. Belter and Calabresa (1950) estimated the total tributary input to Lake Mendota from October 1, 1948 to October 1, 1949. In their study continuous flow measurements were made, but samples for nutrient analysis were obtained only every two to three weeks. In calculating total nutrient inputs they assumed a constant concentration of nutrient between sampling periods.

Two other studies of the tributary nutrient input to Lake Mendota were conducted in the late 1940's, but their results have not been included in Table 3. Bartsch and Lawton (1949) measured the input of nutrients to Lake Mendota via the lake's tributaries over a two year period from 1945 to 1947. Flow measurements were not made on a continuous basis, but just at the time of sampling which was irregular. Their total flow measurements were low compared to measurements made by others (Burgy, 1950 and Cleasby, 1951) despite normal precipitation during the years of their study. This suggests that their tributary nutrient input values, which included base flow and some municipal and industrial wastes, were low (Fruh and Lee, 1965). Thus, the results of Bartsch and Lawton (1949) have not been included in Table 3.

Emelity and Hanson (1949) also measured the total tributary nutrient input to Lake Mendota between July 1, 1948 and May 1, 1949. Again, they did not attempt to differentiate between base flow, runoff and waste water inputs. Although they used continuous flow data, they collected samples only every three weeks and assumed the concentration of nutrients remained constant between sampling periods. Although Emelity and Hanson's (1949) study was not for a full year, they found higher inputs than estimated by Bartsch and Lawton (1949) for a full year.

Thus, the Mendota tributary studies conducted by Bartsch and Lawton (1949), Emelity and Hanson (1949) and Belter and Calabresa (1950) all obtained their samples on a periodic basis. They then assumed that the concentrations of nutrients remained constant between sampling dates. However, it has been shown that a very large amount of nutrients may be carried off during periods of high flow (Kluesener, 1965; Lee, 1969; Zitter, 1969; Taylor *et al.*, 1971). This would be especially important for manure spread on frozen ground, as a large pulse of nutrients would be carried into the receiving stream during a spring thaw. Zitter (1969) found that nutrient loss from rural land was highest during a thaw in February. A heavy June rain also resulted in runoff and high nutrient loss.

Studies on Black Earth Creek by the University of Wisconsin Water Chemistry Program have demonstrated the need for basing the sampling program on stream discharge rather than arbitrary time frequency. Figure 1 shows the discharge-conductance data for Black Earth Creek, (outside Lake Mendota Basin) during the spring thaw in 1965 (Shannon and Lee, 1966). The stream had a base flow from groundwater of approximately 20 cfs for March 29 and 30. During the period of March 30 to April 2, the discharge increased to a peak of 150 cfs on April 1, then gradually receded. Flow during this period was primarily due to snow melt. On April 2 it started to rain; discharge increased to approximately 150 cfs on April 5. After this date, the discharge gradually decreased, approaching base flow after April 13. The specific conductance of the water showed the typical inverse relationship with discharge, with the minimum in specific conductance approximately corresponding to the maximum in discharge. The snow melt and precipitation runoff were low in dissolved salts and diluted the relatively hard groundwater base flow.

Figure 2, on the other hand, shows that maximum phosphate concentration corresponded to the maximum discharge (Shannon and Lee, 1966). As shown in this illustration the snow melt and rainfall runoff contained more phosphorus than did the base flow. This phosphorus was probably derived from manure. The condensed phosphates in the figure were composed of the nonfilterable

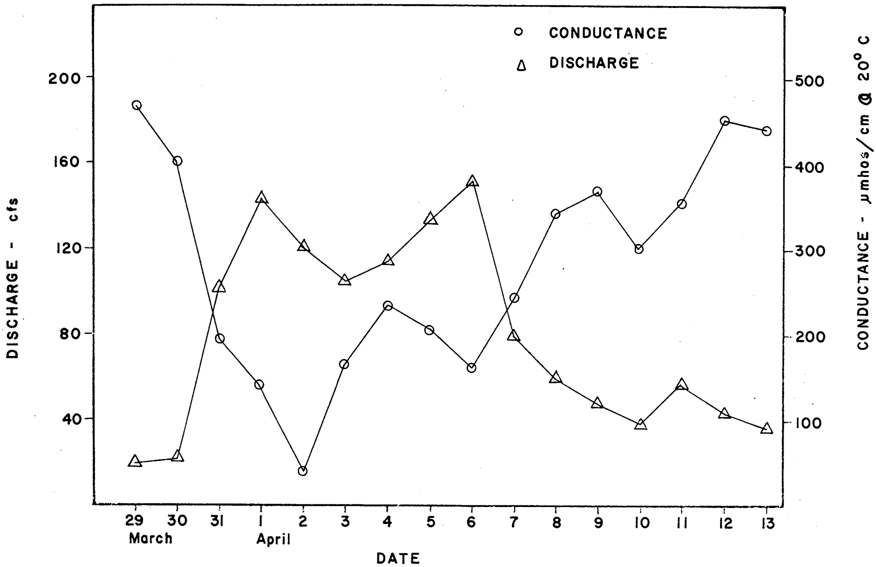

FIGURE 1. Conductance and discharge of Black Earth Creek during spring 1965. (After Shannon and Lee, 1966)

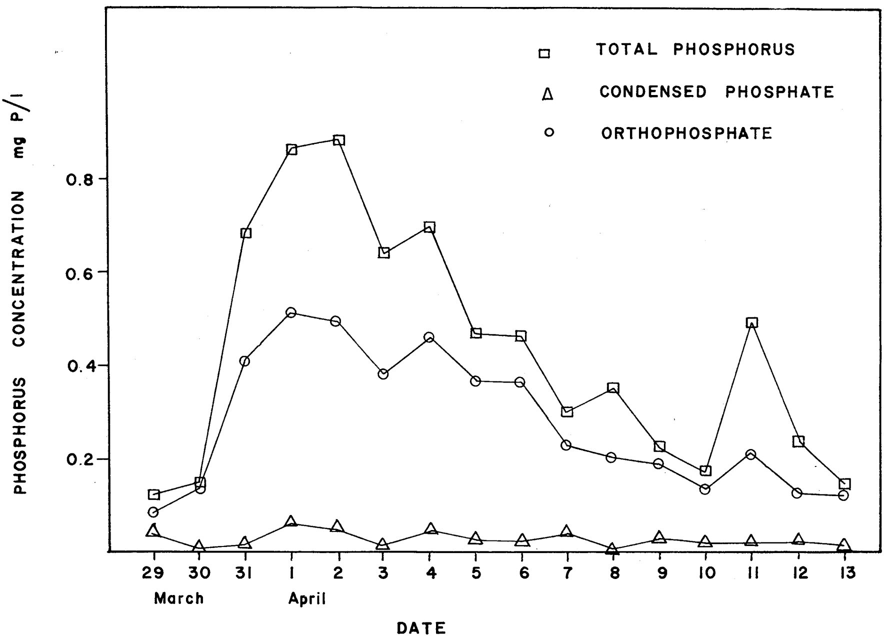

FIGURE 2. Phosphorus concentrations of Black Earth Creek during spring 1965. (After Shannon and Lee, 1966)

phosphorus that is measured by mild acid hydrolysis. No known sources of domestic or industrial pollution were upstream from this sampling station; the condensed phosphates, therefore, were probably organic phosphorus compounds. As expected, an appreciable amount of total phosphorus transported by the stream during spring thaw was particulate phosphate.

The same relation of phosphorus and nitrogen concentration to periods of high discharge was found at all times of the year; the major proportion of these elements were transported during periods of high discharge. Kluesener (1965) found that 65% of the ammonia nitrogen carried annually by Black Earth Creek was carried in just five days during spring thaw. It is important, therefore, to establish a sampling program in which the frequency of sampling increases as the discharge increases. Sampling a stream once every three weeks or even more frequently may not be representative and could result in gross error in computing the amount of plant nutrients contributed by the stream.

Thus, it is likely that the early studies of the Madison lakes may have underestimated nutrient loadings. A possible exception would be the results of Belter and Calabresa (1950), who claimed that samples were collected at peak flows as well as dry weather flows. Hence, the data of Belter and Calabresa (1950), as reported by Gardner (1971), have been included in Table 2.

Table 3 shows that the reported contribution of total-P varies widely, from about 0.1 to 1.0 lb/acre/year, with an average value of 0.58 lb/acre/year. Soluble ortho-P ranges from about 25 to 75% of the total-P, based on the limited data available. Thus, assuming an average loading of 0.6 lb/acre/year for total-P, and assuming soluble ortho-P comprises about one half the total-P, an average value of 0.3 lb/acre/year for soluble ortho-P is obtained.

Total-N ranges from about 1.0 to 10 lbs/acre/year (Table 3) with an average value of approximately 4.5 lb/acre/year. Inorganic-N ranges from about 0.5 to 6.0 lbs/acre/year with an average of about 2.8. The organic-N values range from about 0.5 to 5.0 lbs/acre/year. If an average inorganic-N value is subtracted from the average total-N value, a value of 1.8 lbs/acre/year is obtained for organic-N.

The results from Table 3 may be compared with nutrient loadings for rural lands from other parts of the country. Table 4 lists the results of several North American studies conducted in areas with climates somewhat similar to Wisconsin. When comparing these numbers, one must be aware of the wide variability between experimental methods, soil characteristics, mode of drainage, topography, percolation, and infiltration rates, as well as many other factors. In most cases total tributary input was measured so that base flow and sometimes municipal and industrial waste inputs are included in the nutrient loading figures. At best, the loadings listed in Table 4 are only roughly comparable, but they should prove valuable for delineating a possible range of values.

The results of some literature studies have not been compiled in Table 4. The results of Weidner *et al.* (1969) and Sylvester (1961) are generally an order of magnitude higher than the results in Table 4. Owens (1970) studied the tributary input of English rivers draining rural lands and found that the total-N contribution ranged from 0.5–20 lbs/acre/year and the total-P contribution varied between 0.5 and 2.1 lbs/acre/year. These numbers include base flow but the nutrient concentration from sewage was subtracted. The results of Owens (1970) for England are generally higher than are most North American studies.

Returning to Table 3, it can be seen that the mean value for total-P, 0.6 lb/acre/year, is somewhat higher than that found by most workers in Table 4. The higher value for Wisconsin might

TABLE 4. NUTRIENT LOADING FROM RURAL RUNOFF: ESTIMATES FROM NORTH CENTRAL STATES AND SOUTHERN CANADA

Source & Place of Study	Soluble Ortho—P	Total P	NH_4^+—N	NO_3^-—N	Org—N	Inorg—N	Total—N
			lbs/acre/year				
Engelbrecht & Morgan (1961) Illinois	----	0.2	----	----	----	----	----
Comment: Total—P actually ortho ± hydrolyzable P; includes base flow and waste discharges							
Owen & Johnson (1966) Canada	----	0.21	----	----	----	----	----
Comment: Includes base flow							
Harrow (1966) Canada	----	0.29	----	----	----	----	----
Jaworski & Hetling (1970) Potomac R. basin	----	0.21	----	3.42	----	----	3.8
Comment: Includes base flow							
Holt (1969) Minnesota	0.08	----	----	----	----	1.8	----
Comment: Average for four crop covers; runoff only							
Taylor *et al.* (1971) Ohio	0.06	----	1.3	3.2	----	----	----
Comment: NH_4—N actually reduced N (includes organic amines); includes base flow							
Timmons *et al.* (1968) Minnesota	----	0.21	----	----	----	----	----
Neill *et al.* (1967) Canada	----	----	----	----	----	----	2.8–7.5
Comment: Includes base flow							
Cambell & Webber (1969) Canada	----	0.15	----	----	----	----	----
Mackenthun & Ingram (1967) Ohio	----	0.4	----	----	----	----	----
Comment: Personal communication from Weibel (1965)							

best be explained by the high concentration of dairy farms in the watershed and the then prevalent practice of spreading manure on frozen ground. Minshall *et al.* (1970), Corey *et al.* (1967) and Hensler and Attoe (1970) have discussed the high nutrient yield from manured land. Both Zitter (1969) and Witzel *et al.* (1969) attributed their high total-P values for rural runoff (Table 3) to the spread of manure on frozen ground.

Nutrient budget estimations based on small scale watersheds could have low reliability if extrapolated to cover large areas (Armstrong and Rohlich, 1970). For example, it is possible that not all of the phosphorus which enters a stream in runoff will be carried to a lake. Soil particles suspended during high flow could sorb phosphorus and at some point be deposited along the stream before they reach the lake or ocean. Such a phenomenon has been cited for the high natural fertility for some of the lands in large river basins, such as the lower Nile River. This phenomenon is not thought to be of any importance in the Lake Mendota drainage basin.

Lee (1972) discussed another mechanism by which the soluble inorganic P and N present in a stream at one location may be transformed into non-available (refractory) N and P at some down stream location. A small but definite percentage of the N and P taken up by macrophytes and algae is not remineralized in natural water systems. Based on the various studies it appears that 0.1 to 1.0 lb of total-P/acre/year should provide a range within which the true average value is likely to be found. The range of total-N values for the Madison area agrees reasonably well with those values in Table 4. Data for the different individual forms of nitrogen and phosphorus in Table 4 are rather limited, but generally fall in the range estimated for the nutrient forms in Table 3.

The nutrient loading from rural runoff originally estimated by Lee *et al.* (1966) is compared to the estimates from this report in Table 5. Lee *et al.* (1966) used the data of Eck *et al.* (1957) and Midgley and Dunklee (1945) to arrive at their numbers. Although it was not completely clear in their report, the estimates published by Lee *et al.* (1966) were for soluble forms only. It can be seen that the new estimates (Table 5) are considerably higher than those of Lee *et al.* (1966), especially for nitrogen. However, as shown in Tables 3 and 4, there were no studies that found such a small contribution of nitrogen from rural runoff as Lee *et al.* (1966). Thus, it appears that the estimate for soluble nitrogen made by Lee *et al.* (1966) was low.

More information is really needed on the specific sources of nutrients in rural runoff. The relative significance of manured

TABLE 5. PREVIOUSLY PUBLISHED AND REVISED ANNUAL NUTRIENT LOADING TO LAKE MENDOTA FROM RURAL RUNOFF

	Soluble Ortho—P	Total P	Inorg—N	Total N
		lbs/year/acre		
Lee *et al* (1966)	0.17	----	0.45	----
Revised[1]	0.3	0.6 (0.1–1.0)	2.8 (0.5–6.0)	4.5 (1.0–10)
		lbs/year/whole lake[4]		
Lee *et al.* (1966)	20,000	-------	52,000	---------
Revised[2, 3]	34,000	69,000 (12,000–115,000)	320,000 (58,000–690,000)	520,000 (115,000–1,150,000)

[1]Average value from Table 2 plus predicted range in parenthesis
[2]Based on a rural watershed of 115,000 acres
[3]Average plus predicted range in parenthesis
[4]To the nearest 1,000 pounds

land, different types of cropland, rainfall, etc., as sources of nutrients in rural areas should be determined.

Lee *et al.* (1966) attempted to determine the component of the rural runoff nutrient loading which originates specifically from manured land. This estimate was derived by assuming each of the approximately 20,000 cows in the watershed produces 15 tons of manure in a year and that one-half of this manure is applied during the months of November through March, so that about 150,000 tons will be applied on frozen ground. This amount of manure would cover 15,000 acres if applied at the rate of 10 tons/acre. Lee *et al.* (1966) then used the data of Midgley and Dunklee (1945), which indicated that about 3 lb of N and 1 lb of P were lost from a 10 tons/acre application of manure on an 8% slope in Vermont, to calculate that about 45,000 lb of N and 15,000 lb of P would be lost from manured land in the Mendota watershed. If these very rough figures are compared to the revised estimates in Table 5, it can be seen that about 45% of the soluble phosphorus and 15% of the inorganic nitrogen in rural runoff could be derived from manured lands. It should be kept in mind that this estimate is of low reliability and that more studies on the sources of rural runoff are needed. To be sure, manured lands are a significant contributor to the fertility of agricultural runoff in the Madison, Wisconsin area.

Urban Runoff

The annual amount of nutrients entering Lake Mendota per acre of urban drainage was estimated from Kluesener (1972). The study consisted primarily of intensive sampling for short periods of time on a small urban section of the watershed of Lake Wingra, one of the Madison lakes. It is felt that this study concurrently presents the best estimate of the nutrient content of urban runoff for the Madison area. Kluesener (1972) has compared the results of his study with previous studies of urban runoff and found general agreement with most of the previous studies in the area.

A comparison of the estimates of Kluesener (1972) and those of Lee *et al.* (1966) for urban runoff is given in Table 6. It can be seen from the revised estimates that more nutrients are entering Lake Mendota from urban runoff than previously thought.

Although Kluesener (1972) did not determine the relative amounts of nutrients derived from various urban activities, he did point to the importance of leaves and seeds from trees as phosphorus sources in urban runoff. Recently, Cowen and Lee (1971) followed up Kluesener's preliminary investigation on the role of leaves as a source of phosphorus in urban drainage. They found that inorganic phosphorus was rapidly leached out of leaves collected in early autumn. Even leaves weathered by rain water or lake water contained significant amounts of leachable phosphorus. In general, they found that each gram of leaves may potentially fertilize many liters of water above the critical concentrations of phosphorus often cited as causing excessive growths of aquatic plant or algae in natural waters. Hence, leaves and seeds and flowers must be considered as a major contributor to the relatively high concentrations of phosphorus found in urban drainage.

Atmospheric Precipitation and Dry Fallout

Kluesener (1972) measured the nutrient content of rain and snowfall as well as dry fallout during his study of Lake Wingra. If it is assumed that his results are typical of the Madison area,

TABLE 6. PREVIOUSLY PUBLISHED AND REVISED ANNUAL NUTRIENT LOADING TO LAKE MENDOTA FROM URBAN RUNOFF

	Soluble Ortho—P	Total P	NO_3^-—N	NH_4^+—N	Organic N	Total N
			lbs/acre/year			
Lee *et al.* (1966)	0.51	----	----	----	----	1.9 (soluble)
Revised	0.57	0.98	0.60	0.45	3.5	4.6
			lbs/year/whole lake[1, 2]			
Lee *et al.* (1966)	8,000	------	------	------	------	30,000 (soluble)
Revised	9,000	16,000	10,000	7,000	56,000	73,000

[1]Based on an urban watershed of 16,000 acres for Lake Mendota
[2]To the nearest 1,000 pounds

his data may be used to reestimate this source of nutrients to Lake Mendota, assuming an average rainfall of about 30 inches.

A comparison of the estimates based on Kluesener (1972) and those of Lee *et al.* (1966) for atmospheric precipitation and dry fallout are presented in Table 7. The revised estimates when dry fallout and atmospheric precipitation are totaled are significantly higher than the contribution originally published.

Groundwater Seepage

Unfortunately, very little information is available on the groundwater nutrient input to Lake Mendota by direct seepage into the lake. The previously published estimates (Lee *et al.,* 1966) were based primarily on a report by Cline (1965). Cline (1965) estimated that 80% of the total atmospheric precipitation on the watershed is consumed by evapotranspiration and that almost none of the ground water is lost from the watershed by underflow. If the average annual atmospheric precipitation amounts to about 30 inches/year, then about 6 inches will be divided between runoff and percolate. Assuming about 2 inches will run off the surface, an average of about 4 inches, or about 65 cfs over the entire watershed, should enter the ground as percolate each year. Cline (1965) thus estimated that about 30 cfs of this enters the lake directly each year, the rest contributing to the flow of surface tributaries (base flow). The roughness of these estimates was emphasized in the original report by Lee *et al.* (1966). Further, C. L. R. Holt, Jr. (personal communication), district geologist of the U.S. Geological Survey, has indicated that the previous esti-

TABLE 7. PREVIOUSLY PUBLISHED AND REVISED ANNUAL NUTRIENT LOADING TO LAKE MENDOTA FROM ATMOSPHERIC PRECIPITATION AND DRY FALLOUT

	Soluble Ortho—P	Total P	NO_3^-—N	NH_4^+—N	Organic N	Total N
			lbs/year/acre			
Lee *et al.* (1966)	----	0.01–0.78	----	----	----	10.0
Revised						
Atmospheric precipitation	0.16	0.21	2.9	2.5	1.7	7.1
Dry fallout	0.13	0.72	3.1	3.6	7.2	13.9
			lbs/year/whole lake[1, 2]			
Lee *et al.* (1966)	-----	140–7,600	------	------	------	97,000
Revised						
Atmospheric precipitation	2,000	2,000	28,000	24,000	17,000	69,000
Dry fallout	1,000	7,000	30,000	35,000	70,000	135,000

[1]Based on a lake surface of 9,730 acres
[2]To the nearest 1,000 pounds

mates based on Cline (1965) for total ground water input to the lake are not very accurate. Nevertheless, using this estimated ground water inflow and a concentration of 2.5 mg/l of NO_3^-—N (based on the data of Eck, 1958, and Domogalla *et al.*, 1926) and 0.01 mg/l P (based on the phosphorus concentration found in a well on the western shore of the lake), Lee *et al.* (1966) concluded that about 171,000 lbs of NO_3^-—N and 600 lbs of P enter the lake via ground water seepage each year.

Unfortunately, even if the ground water inflow to the lake and the chemical composition of the ground water at some point up gradient from where it emerges into the lake were known with some degree of certainty, a reliable estimate of the amounts of nutrients contributed via the ground water could not be easily obtained (Lee and Kluesener, 1971). This is due to the fact that information must be available on the manner in which the ground water enters the lake. If entry is primarily through sand, submerged springs, or other areas in which there is little or no lake sediment, then most of the nutrients present in the ground waters would be transported to the lake. However, if the entry is through the sediments of the lake, it can be expected that at certain times of the year some of the phosphorus present in the sediments through which the water enters would be removed by sorption reactions in the sediments. At other times, it is possible that this ground water might tend to displace interstitial waters, which may be high in phosphorus, into the lake. In the case of nitrogen as NO_3—N, it is reasonable to expect that in those areas of the sediments where the oxygen concentration is low, there should be significant denitrification which would tend to reduce the amounts of available nitrogen that enter the lake water from that which was predicted based on total ground water input.

Recently, Keeney *et al.* (1971) investigated the importance of denitrification in Lake Mendota sediments to the nitrogen budget of the lake. Based on experiments with samples of surface sediments from 7 and 14 meters, they estimated that about 63% of the nitrate-nitrogen entering Lake Mendota will be denitrified. Thus, they estimated that the nitrogen entering Lake Mendota via ground water seepage to be only 63,000 lbs/year vs. the original estimate of 171,000 lbs/year.

The approach used by Keeney *et al.* (1971), however, may grossly overestimate the significance of sediment denitrification as a process reducing the amount of nitrogen input into lakes. Based on the hydrology of the Lake Mendota basin and in particular the ground waters around the lake (see Dane County Planning Commission, 1971), it would be expected that significant amounts of shallow ground water enter the lake through the sides of the lake near the surface. Furthermore, considerable amounts of ground water are entering the lake through fissures in limestone outcrops, as evidenced by divers working under the direction of the senior author. Ground water entering through the sides of the lake and through fissures would probably not be exposed to the anoxic sediments which would lead to rapid denitrification as reported by Keeney *et al.* (1971). If ground water entered the lake through the deeper sediments under anoxic conditions, it would be correct to expect rapid denitrification, as demonstrated earlier by Brezonik (1965); however, it is unreasonable to reckon that significant amounts of ground water enter Lake Mendota through these deep sediments.

It is almost impossible to utilize any measurements of the rates of denitrification in sediments to obtain a reliable estimate of how much of the nitrogen entering a lake is lost through this reaction without very good information on the hydrology of the ground water, and in particular how the ground water enters the lake. Presumably some denitrification of ground water does occur so that the ground water input of nitrogen would probably be less than the original estimate of Lee *et al.* (1966) report. Brezonik and Lee (1968) have shown that denitrification in the anoxic waters is a relatively small but significant sink in the nitrogen budget for Lake Mendota. About 62,000 lbs of nitrogen were lost from the lake hypolimnion during the summer of 1966. This would also tend to reduce the input of nitrogen from ground water. However, without a better understanding of the hydrology of ground water seeping into the lake, it is not felt justifiable to change the original estimate (Lee *et al.*, 1966) of the amounts of nitrogen and phosphorus contributed by ground water seepage into the lake. The lack of information of the relative nutrient contribution of ground water seepage to the total nutrient budget is one of the greatest deficiencies of the proposed nutrient loading estimations for Lake Mendota. This is especially true for nitrogen. Because of the relatively high concentrations of nitrate present in ground water in the Madison area, ground water must be considered as a potentially important source of nitrogen to Lake Mendota.

Nitrogen Fixation

The amount of nitrogen fixed in Lake Mendota was most recently studied by Torrey (1972). Nitrogen fixation was based on the acetylene reduction method, assuming a ratio of 3:1 for the rate of acetylene reduced to nitrogen reduced. Estimates of nitrogen fixation in Lake Mendota in the past were based on limited experiments using fixation of $^{15}N_2$.

Torrey (1972) reported that about 88,000 lbs of nitrogen were fixed each year during 1970 and 1971 and this value will be used to reestimate nitrogen fixation in Lake Mendota. This compares with the estimate previously published by Lee *et al.* (1966) of 80,000 lbs of N/year; subsequently, it was found that an error had been made in the computation of this figure and in 1969 the figure was revised to 2000 lbs of N/year.

Torrey (1972) found that most of the nitrogen was fixed by blue green algae in the surface waters during the summer months when combined nitrogen available for algal growth is low. However, some fixation was found to occur in the sediments of Lake Mendota. While this was thought to be small compared to the total fixation that occurs in the surface waters, this fixation would tend to counteract to some degree the denitrification reactions that potentially take place as a result of anoxic conditions in some of the sediments. Finally, it should be mentioned that the results of Torrey (1972) do not include nitrogen fixation occurring in marsh land bordering the lake or in littoral areas. Current studies by Lonergan, graduate student, U. W. Water Chemistry Program, show that potentially significant amounts of nitrogen fixation occur in marshes.

Marshland

Bentley (1969) studied several marshes in the Madison vicinity in order to estimate their nutrient contribution. On a yearly basis he found that the nutrient input to a marsh was approximately equal to its nutrient output. Apparently, nutrients flowing into marshes from surface sources during most of the year are held by the marsh. However, during spring thaw all of the nutrients stored by the marsh are released with the high spring flows. Thus, based on the study of Bentley (1969), the marshland within the Mendota watershed is not thought to be nutrient sink, when a full year cycle is considered.

Studies of the amounts of nutrients derived from drained marshes by Bentley (1969), Amundson (1970) and Lee *et al.* (1971) have shown that the drainage of a marsh can potentially represent a major source of nitrogen and phosphorus. Laboratory studies have shown that large amounts of inorganic nitrogen and phosphorus can be leached from drained marsh soil in a period of several years. Since there has been no significant drainage of marshes in the Lake Mendota basin during the past five years, it is felt that the large amount of marsh drainage that has occurred previous to this time is not presently contributing consequential amounts of nutrients to the lake. Therefore, no attempt will be made in the current estimate of nutrient sources to include the potential effects of previously drained marshes.

Woodland

Kluesener (1972) has reviewed the possible contribution of nutrients in runoff from woodland. In general, he concluded that surface runoff from woodland would be insignificant. Kelling (1972) found that prairies and forests in the Madison vicinity were able to infiltrate rain applied with a sprinkling infiltrometer at the rate of 5 in/hr. Hence, little surface runoff would be expected in these areas. However, there might be a contribution of nutrients to base flow sustained by groundwater in the forested regions, although it would probably be less than in rural areas. Because the highly cultivated Mendota watershed has few remaining wooded areas of any size, the total nutrient contribution from woodland will be considered negligible.

Waste Water Effluents

The nutrients contributed annually to Lake Mendota from the waste water effluents of several small municipalities, as well as several industries, were estimated by Lee *et al.* (1966). Some of the sources were eliminated late in 1971 when certain waste waters were diverted to the Madison Metropolitan Sewage District system so that they ceased to enter Lake Mendota. However, in order to properly evaluate the significance of the diversion, it is necessary to reestimate, based on population increases, and other new information, the quantities of nutrients contributed by waste water sources immediately prior to diversion. Thus the nutrients contributed by waste waters in 1970 (prior to diversion), as well as the sources remaining following the diversion, will be discussed.

The Morrisonville Sanitary District currently operates a sewage system consisting of a two-cell stabilization pond. The Wisconsin Department of Natural Resources (1971) reported that only on one occasion was there noted an overflow to the Yahara River, a Mendota tributary. The district is not thought to be a significant nutrient source at the present time.

The Village of DeForest has a trickling filter treatment plant which, up until December, 1971, handled domestic waste from the village in addition to wastes from the Forest Milk Company. Treated wastes were discharged to the Yahara River. A survey (Wisconsin Department of Natural Resources, 1971) in 1970 showed a daily total waste volume of 200,000 gal/day and an estimated BOD of 167 lbs/day. The plant was reported to be badly overloaded. In the winter of 1965 Lee *et al.* (1966) reported a daily total waste volume of about 135,000 gallons, of which the milk plant contributed about 35,000 gallons containing a BOD load of 553 lbs/day. In October, 1962, a 24 hour survey found a total daily flow of 74,800 gallons containing 174 lbs/day of BOD; however, the milk plant was not operating during the survey. According to decennial census reports, the village population increased from 1,223 in 1960 to 1,911 in 1970.

The Town of Windsor Sanitary District No. 1 currently[1] operates a trickling filter treatment plant which discharges into the Yahara River. In 1960 the estimated population of the district was 350. In 1969 the population of the district was estimated at 550 (Wisconsin Department of Natural Resources, personal communication). A 24 hour-study on September 9 and 10, 1969 found that the treatment plant removed only 67.7% of the BOD and 57.5% of the suspended solids (Wisconsin Department of Natural Resources, 1971). The 24 hour study also revealed the following nutrient data:

	mg/l
Soluble P	11.6
Total-P	16.5
Org-N	8.6
NH_4^+—N	21.2
NO_3^-—N	< 0.3
NO_2^-—N	1.2
T-N	31.0

The flow at this time was about 50,000 gal/day and the BOD was 30 lbs/day.

The Village of Waunakee, up until December, 1971, employed a trickling filter to treat sanitary sewage from the community. A 24 hour survey in the summer of 1962 revealed a flow of 148,500 gal/day which contained a BOD of 212 lbs/day and the following concentrations of nitrogen: organic N, 7.4 mg/l; NH_4^+—N, 15.6 mg/l; NO_2^-—N, 1.64 mg/l; NO_3^-—N, 3.64 mg/l (Lee *et al.*, 1966). A survey in 1970 showed a flow of 220,000 gal/day and a BOD of 121 lbs/day (Wisconsin Department of Natural Resources, 1971). In 1960, the Village of Waunakee had a population of 1,611, while the 1970 census indicated the population had increased to 2,181.

The Waunakee Cheese Factory disposes of its milk wastes in a seepage lagoon within the Village of Waunakee. Sodium nitrate has been added at times to aid in odor control. The Waunakee Canning Company also disposes of wastes seasonally by means of spray irrigation. It has been reported (Wisconsin Department of Natural Resources, 1971) that runoff from the spray irrigation sometimes enters the drainage course.

[1] Since preparation of this report this waste water has been diverted to the Madison Metropolitan sewage system.

In Madison the Avenue Car Wash rinse water is no longer a nutrient source as it was diverted to the sewage line and thus around the Madison lakes prior to 1970. However, a new nutrient source not reported by Lee *et al.* (1966) is the Pure Oil Truck Plaza, which is located along the interstate highway system. The plaza discharges its treated domestic wastes to Token Creek, a tributary to Lake Mendota. The wastes are treated by a package aeration plant and are chlorinated before discharge (Wisconsin Department of Natural Resources, 1971). The truck stop discharges 10,000 gal/day of treated effluent, which has a BOD of about 5 lbs/day. Since the volume of domestic waste water in the United States averages 100 gpdc (Fair *et al.*, 1968) a population equivalent of about 100 is calculated.

Since little additional information is available on the industrial sources of nutrients, the original estimate will continue to be used minus the contribution (625 lbs/year of phosphorus) from the Avenue Car Wash. Thus, the estimated total contribution from industrial waste sources for 1970 was about 17,000 lbs of nitrogen per year and 9,000 lbs of phosphorus per year as shown in Table 8. These values will be assumed to represent total-N and total-P, although the form of the nutrients was not specified by Lee *et al.* (1966). Since the municipally treated wastes from the Forest Milk Company comprise most of the industrial loading, it is probable that organically combined forms of the nutrient were important. Hence, half of the total-N and total-P will be estimated to have been in an organic form.

The contribution of nutrients from treated domestic wastes was computed by Lee *et al.* (1966), from a per capita annual contribution of 1.7 lbs of phosphorus and 7 lbs of nitrogen. Although it

TABLE 8. INDUSTRIAL WASTE SOURCES ENTERING LAKE MENDOTA—1970
(After Lee *et al.* (1966)

	Total-P	Total-N
	lbs/year	
Forest Milk Company		
Municipally treated wastes	9,000	13,000
Waunakee Cheese Plant		
Municipally treated wastes	200	700
Lagoon seepage		3,000
Waunakee Canning Company		
Spray irrigation overflow to streams	100	100
Total	9,300	16,800

was not specified in the original report (Lee *et al.*, 1966), these numbers referred to soluble-orthophosphate and inorganic nitrogen.

In order to gain insight as to the quantity of the different forms of nutrients in the effluents, the previously discussed results of 24 hour nutrient surveys of the Waunakee and Windsor treatment plant effluents may be utilized. Assuming that the concentrations reported were typical, the annual per capita nutrient contributions from these sources have been estimated. The results are listed in Table 9. The Nine-Springs Sewage Treatment Plant, which provides primary and secondary treatment for wastes from Madison, has an effluent with an average annual per capita contribution of 8.5 lbs of inorganic nitrogen and 3.5 lbs of soluble phosphorus (Mackenthun and Ingram, 1967).

Based on these limited data, the following annual per capita contributions will be used to reestimate the quantity of nutrients supplied by treated sewage effluent: soluble ortho-P, 3 lbs/cap/yr; total-P, 4.5 lbs/cap/yr; inorganic-N, 6 lbs/cap/yr; organic-N, 2 lbs/cap/yr; total-N, 8 lbs/cap/yr. Using these values and the latest census information or population estimates, the 1970 annual contribution of nutrients from treated domestic wastes has been computed and the results are presented in Table 10.

The revised estimates of total nutrients contributed by waste water in 1970 are compared to the originally published contribution in Table 11. It can be seen that the revised estimates are considerably higher than those previously reported for both phosphorus and nitrogen.

One other waste water source must be considered, that being the discharge from private domestic disposal systems (septic

TABLE 9. ANNUAL PER CAPITA NUTRIENT CONTRIBUTIONS FROM THE WAUNAKEE SEWAGE TREATMENT PLANT AND THE WINDSOR TREATMENT PLANT (SANITARY DISTRICT #1)

	Waunakee[1]	Windsor[2]
	lbs/capita/year	
Soluble ortho-P		3.2
Total P		4.6
NH_4^+—N	4.4	5.8
NO_2^-—N	0.5	0.3
NO_3^-—N	1.0	negligible
Org-N	2.1	2.4
Total-N	8.0	8.5

[1] Based on a 24 hour study in 1962
[2] Based on a 24 hour study in 1969

TABLE 10. ESTIMATED NUTRIENT LOADING TO LAKE MENDOTA FROM TREATED DOMESTIC WASTES FOR 1970

Source	Estimated Population	Soluble O—P	T—P	Inorg N	Org N	T—N
Waunakee	1,911	5,700	8,600	11,500	3,800	15,300
DeForest	2,181	6,500	9,800	13,100	4,400	17,500
Windsor	550	1,600	2,500	3,300	1,100	4,400
Truck Plaza	100	300	400	600	200	800
Total	4,742	14,100	21,300	28,500	9,500	38,000

TABLE 11. PREVIOUSLY PUBLISHED (LEE *ET AL.* 1966) AND 1970 ANNUAL NUTRIENT LOADING TO LAKE MENDOTA FROM MUNICIPALLY TREATED WATERS

	Lee *et al.* (1966)	Revised[1] (1970)
	(lbs/year)	
Soluble ortho-P	6,460	14,000
Total-P		21,000
Inorganic-N	26,600	28,000
Organic-N		10,000
Total-N		38,000

[1] To the nearest 1000 pounds

tanks). Septic tanks are generally a problem only if they become plugged, which is likely to occur fairly frequently in non-sandy soils, found in much of the Mendota basin. When this occurs surface discharge may result and nutrients in the effluent can be transported via overland flow to the lake. Lee *et al.* (1966) estimated the annual discharge by assuming a population of 500 having malfunctioning septic tanks and by using the same nutrient loading rate as used for treated domestic waste. Again, the form of the nutrients supplied by this source was not specified by Lee *et al.* (1966). In revising this source, no organic forms will be considered. The per capita contribution will be assumed to be the same as for municipally treated domestic sewage. Therefore, again estimating a population of 500 (this is perhaps an overestimation, the number of malfunctioning septic tanks being unknown), the source should provide about 1500 lbs of soluble ortho-phosphorus and 3,000 lbs of inorganic nitrogen.

The total annual nutrient loadings as of 1970, from the three types of waste effluents—municipally treated domestic wastes, privately treated domestic wastes, and treated industrial wastes—

TABLE 12. PREVIOUSLY PUBLISHED AND 1970 ANNUAL NUTRIENT LOADING TO LAKE MENDOTA FROM WASTE WATER EFFLUENT

	Lee *et al.* (1966)	Revised[1]
	(lbs/year)	
Soluble ortho-P		21,000
Total P	17,000	32,000
Inorganic-N		41,000
Organic-N		19,000
Total N	47,000	60,000

[1] To the nearest 1000 pounds

are compared to the previous published estimates of Lee *et al.* (1966) in Table 12. The revised estimate represents more than a 50 percent increase over the previously-predicted loading.

Beginning in December, 1971, the Madison Metropolitan Sewerage District completed an extension of their system which transports the waste water of Waunakee and DeForest to the Nine Springs treatment plant so that the waste effluent from these communities is now diverted around Lake Mendota. Therefore, with the completion of the extension to Windsor, which is scheduled for the near future, all major waste water sources will be eliminated. The estimates of the relatively insignificant waste water nutrient sources remaining after diversion are presented in Table 13.

TABLE 13. REMAINING WASTE WATER NUTRIENT SOURCES FOR LAKE MENDOTA FOLLOWING ELIMINATION OF TREATED WASTE WATER DISCHARGES FROM WAUNAKEE, DeFOREST AND WINDSOR

	Soluble Ortho-P	T-P	Inorg N	Org N	T-N
			lbs/year		
Truck Plaza	300	400	600	200	800
Waunakee Cheese Plant Seepage Lagoon			3,000		3,000
Waunakee Canning Company		100			100
Septic Tank	1,500	1,500	3,000		3,000
Total		2,000			6,900

TABLE 14. ESTIMATED NUTRIENT SOURCES FOR LAKE MENDOTA—REVISED (PRIOR TO DIVERSION OF WASTE WATER EFFLUENTS)

	Soluble O—P	Total P	NH^{+}—N	NO_3^{-}—N	Org N	Total N	% Estimated Contribution	
							Total P	Total N
	lbs/year (to nearest 1,000 lbs)							
Waste water discharge	21,000	32,000	41,000[1]		19,000	60,000	23	5
Urban runoff	9,000	16,000	7,000	10,000	56,000	73,000	11.5	6
Rural runoff	34,000	69,000	320,000[1]		200,000	520,000	50	42
Possible range		(12,000–115,000)	(58,000–690,000)[1]			(115,000–1,150,000)		
Precipitation on lake surface	2,000	2,000	24,000	28,000	17,000	69,000	1	5.5
Dry fallout on lake surface	1,000	7,000	35,000	30,000	70,000	135,000	5	11
Ground water seepage	1,000	1,000		171,000		171,000	0.5	13.5
Base flow	12,000	12,000		135,000		135,000	9	11
Nitrogen fixation					88,000	88,000		7
Woodland runoff	0[2]	0	0	0	0	0	0	0
Marsh drainage	0	0	0	0	0	0	0	0
Total	80,000	139,000	801,000		450,000	1,251,000		

[1]Inorganic nitrogen
[2]Negligible

Summary of Revised Estimates

The revised annual nutrient contributions from the various sources (prior to the diversion of waste water effluents) have been summarized in Table 14. It can be seen that the revised annual contributions of nitrogen and phosphorus have been more than doubled, as compared with the old estimates.

In the case of phosphorus, the per cent contribution of the various sources changed little. The major changes were in rural runoff, which increased from 42% to 50%, and in municipal and industrial waste water, which decreased from 36% to 23%. In the case of nitrogen, the major changes were in rural runoff and ground water seepage. The contribution of rural runoff increased from 11% to 42%, while the ground water contribution from direct seepage decreased from 36% to 14% in the revised estimate.

In computing the annual contribution from rural runoff, average lbs/acre values from Table 3 (discussed in a previous section) were used to compute total nutrient input and the per cent estimated contribution in Table 14. However, because rural runoff appears to be the major nutrient source, a possible range of values was also tabulated in Table 14 (see previous section on rural runoff). Even if the minimum values suggested were used, the percentage of nutrients contributed by rural runoff would still be significant and the sum total nutrient input in lbs/year would remain greater than the previous estimate of Lee *et al.* (1966). For example, if the minimum predicted contribution of total phosphorus from rural runoff (as listed in Table 14) were used to predict the annual phosphorus input, the total input would decrease to 81,000 lbs/year, still higher than the previously published estimate. However, the total phosphorus contribution of municipal and industrial wastes would increase to nearly 40%, while the rural runoff contribution would decrease to about 20%. On the other hand, if the maximum possible contribution for rural runoff were used to compute the total phosphorus input, rural runoff would be by far the dominant source of phosphorus.

Estimated nutrient sources for Lake Mendota after the diversion of waste water effluent from the communities Waunakee, De-Forest, and Windsor are given in Table 15. It can be seen that the diversion will decrease the phosphorus loading by about 20% and the nitrogen loading by about 4%.

Finally, it should be emphasized that the revised estimates are predicated on many assumptions and are, at best, still only rough approximations. This is especially true of the total nitrogen loading, since the estimate of nitrogen influx due to groundwater seepage, although listed as a major nitrogen source in Table 15, is based on very limited information and is subject to considerable error.

TABLE 15. ESTIMATED NUTRIENT SOURCES FOR LAKE MENDOTA FOLLOWING ELIMINATION OF TREATED WASTE WATER DISCHARGES FROM WAUNAKEE, DeFOREST AND WINDSOR

	% Estimated Contribution	
	T-P	T-N
Waste water discharges	2	1
Urban runoff	14.5	6
Rural runoff	63	43.5
Atmospheric precipitation on lake surface	2	6
Dry fallout on lake surface	6.5	11
Ground water seepage	1	14
Base flow	11	11
Nitrogen fixation		7.5
Woodland runoff	0[1]	0
Marsh drainage	0	0

[1] Negligible.

Nonetheless, the revised estimates are believed to be the most current and reasonable estimates based on the data available.

Control of Nutrient Sources

The most easily controlled sources of nutrients are the point sources, such as the discharge of waste water. In effect, the major point sources for Lake Mendota were controlled with completion of the sewage interceptor which diverted waste water from Waunakee and DeForest to the Nine Springs Plant. Further elimination of waste water sources, such as the Town of Windsor sewage effluent or the effluent from the Pure Oil Truck Stop, will have a relatively minor effect on the total nutrient flux to the lake. In fact, the diversion of waste water from Waunakee and DeForest resulted, in the case of phosphorus, in a nutrient input reduction of only about 20%. This is not to say that the elimination of these sources is not of value. On the contrary, their elimination serves as a preventive measure to avoid future degradation of the water quality of the lake. This degradation could ensue if waste water, which would steadily increase in amount as a result of the rapidly expanding population on the north and west side of the lake, were to continue to be discharged into the lake.

Since nutrients entering Lake Mendota are derived to a significant extent from a variety of sources (such as urban storm water drainage and agricultural runoff), increased attention should be given to the control of these diffuse sources of phosphorus. Because of their diffuse nature, chemical treatment of these sources will be extremely expensive, quite probably prohibitive. Rather than attempting to collect and treat drainage waters from urban and agricultural areas, a more fruitful approach might be to study in detail specific sources of nutrients in urban and agricultural areas, and then attempt to control the specific source at its origin. For example, it is known that urban storm water drainage contains large concentrations of phosphorus. At the present time, essentially nothing is known about the specific sources of phosphorus in the urban environment. The mass balance approach needs to be made in a number of urban communities throughout the United States in order to determine the relative significance of lawn fertilization, gasoline combustion, dust fall, terrestrial plants, etc., as sources of phosphorus in urban areas.

As mentioned previously, Kluesener (1972) noted that the highest concentrations of phosphorus in the urban stormwater drainage were associated with the leaf fall period during the fall and Cowen and Lee (1971), in a follow-up study on leaves as a source of phosphorus, found that large amounts of phosphorus are readily leachable from dead leaves. It appears, based on these preliminary studies, that more effective leaf pick-up during the fall might minimize the amounts of nutrients derived from this source in urban stormwater drainage.

Agricultural sources of nutrients could be controlled through education of the farmer, in terms of when to apply nutrients, what concentrations to apply and how to control soil erosion and other conditions that tend to promote high nutrient fluxes from farmland. The manure problem that exists in Wisconsin and other nearby states can be controlled by having the farmer store the manure in tanks over the winter period and then spread it on the land after the ground has thawed in the spring.

One of the methods beginning to be used for controlling agricultural and urban stormwater drainage is zoning for land use. In Wisconsin there has been recent action by the Dane County Planning Commission which is specifically designed to prevent urban development in Lake Mendota's watershed because of the fear that the conversion of farm land to urban areas would increase the nutrient flux to this lake. Further, Illinois is considering legislation which prevents certain types of fertilizer application on lands with a slope greater than a certain degree. Another example of this type of development is the current legislation being considered on the Lake Mendota drainage basin. The proposed guidelines would prevent the winter spreading of manure from dairy operations and the draining of marshland for agricultural or urban use. It is likely that these developments in Wisconsin and Illinois will set the pattern for similar developments throughout North America.

It is of interest to examine the potential effect of future urbanization of Lake Mendota's watershed. The Dane County Planning Commission (private communication, 1972) has estimated that the urban area within the Lake Mendota watershed will roughly double in size by 1990 (the increase will vary somewhat according to the growth rate projection used). Assuming the urban area doubles by 1990 at the expense of rural land, an estimate of the total phosphorus loading can be obtained using loading factors of 0.6 lb/acre/year (Table 3) for rural runoff and 1.0 lb/acre/year for urban runoff (Table 6) can be made, if other nutrient sources remain at the same rate as present. In this manner it is predicted that urban runoff will contribute 28% of the annual total phosphorus loading, while rural runoff will contribute 51% in 1990. These percentages compared with 14.5 and 63% respectively, for 1972 (Table 15), indicate that the sum total annual phosphorus loading from all sources should increase from the present rate of 109,000 pounds per year to 115,000 pounds per year in 1990, an increase of about 6%. The total loading predicted for 1990 is still less than the total loading estimated for 1970 (prior to the 1971 diversion). Therefore, based on the above analysis, it does not appear that doubling the urbanized area within the Lake Mendota watershed will have a major effect on the water quality of Lake Mendota.

It should be noted that not all conversions of agricultural lands to urban areas would necessarily result in an increase in nutrient flux, since some rural areas, such as heavily manured lands, could conceivably result in little or no decrease in the nutrient flux when the land is converted to urban areas. On the other hand, the effect of urbanization would likely be of greater magnitude than reported, if the new urban areas were at one time marshland, since, as was discussed previously, the drainage of marshes results in a very significant release of nitrogen and phosphorus to the drain water (Lee *et al.*, 1971). This release probably takes place over a period of several years and it is estimated that marshes of the type found in southeastern Wisconsin would yield on the order of 40 pounds of phosphorus per acre.

Nutrient Availability

In addition to determining the amounts of nutrients derived from various types of activities of man in urban and agricultural areas, studies must be initiated to determine what part of the nutrients from these sources is or can be made available for aquatic growth. For example, some urban and agricultural activities contribute large amounts of total phosphorus; however, a large portion of this phosphorus is in a form, i.e., particulate, organic, etc., that is not immediately available for the growth of algae. A much better understanding must be achieved on the aqueous environmental chemistry of particulate, inorganic, and organic forms of nutrients in order to ascertain the real significance of the various forms of nutrients derived from urban and agricultural areas in stimulating the growth of aquatic plants and algae. Studies along this line are currently underway at the University of Wisconsin Water Chemistry Program.

In the case of phosphorus, about the best that could be done at this time is to state that in most instances the available phosphorus is somewhere between soluble orthophosphate and the total phosphorus. The fraction of organic and particulate phosphorus that becomes available in natural waters is extremely important in designing meaningful eutrophication control programs for diffuse sources of nutrients. There is little point in attempting to control particulate forms of phosphorus when it is known that the phosphorus would not become available for algal growth under the conditions existing in the receiving waters. The potential availability of the nitrogen species are even less well known.

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AN EVALUATION OF THE USE OF THE EEG TECHNIQUE TO DETERMINE CHEMICAL CONSTITUENTS IN HOMESTREAM WATER

Jon C. Cooper
University Wisconsin—Madison
G. Fred Lee
University Texas—Dallas
and
Andrew E. Dizon
National Marine Fisheries Service
Honolulu—Hawaii

INTRODUCTION

A large body of literature now exists that points to olfaction in migratory fish as the important sense in orientation near and in the homestream (Collins *et al.*, 1962; Fagerlund *et al.*, 1963; Groves *et al.*, 1968; Hasler, 1960a, 1960b, and 1966; Hasler and Wisby, 1951). It is hypothesized that salmon can store odor information about the homestream and use these cues upon the homing migration.

The chemical or chemicals involved in homestream cues are probably of a very low concentration and perhaps a complex mixture. Efforts to determine these chemicals have met with some success. Fagerlund *et al.* (1963) found that a portion of these chemicals is volatile, although the non-volatile portion may play some part in orientation for the fish. Hasler (1966) reported that the active fraction was organic, heat labile and volatile at 25 C. Idler *et al.* (1961) concluded that the material was neutral, dialyzable and heat labile.

Hara *et al.* in 1965 reported that homestream water perfused through the nares of salmon produced a characteristic high amplitude wave in an electroencephalographic (or EEG) recording from the olfactory bulb. The EEG, they suggested, might be used to study on a physiological basis the olfactory hypothesis.

Since the EEG had been looked on as a possible bioassay for individual homestream recognition (Oshima *et al.*, 1960a and b; Ueda *et al.*, 1967), it was felt that the EEG might provide useful information about homestream chemicals that were needed for homing. Because the technique is quite recent, this problem was first approached by repeating earlier experiments by Fagerlund *et al.*, Hasler, and Idler *et al.* Although the active fractions described by these workers may not be the same as the stimulants in the EEG experiments, it was felt that there should be some correspondence in the groups of chemicals described in the two types of experiments. This paper reports on an investigation designed to evaluate the feasibility of using EEG as a means of detecting the chemicals present in homestream water that are responsible for the homing of coho salmon in a Wisconsin stream bordering on Lake Michigan.

METHODS

Adult spawning coho salmon *(Oncorhynchus kisutch)* that had homed to a tributary of the Ahnapee River, Algoma, Wisconsin in the fall, 1970, were used in these studies. They were trapped in the stream on the same day as the experiments and brought back to a temporary laboratory, where they were held in city tap water.

The testing procedure was similar to that of Dizon *et al.* (1973). The fish were anesthetized with tricain methanesulphonate (MS222, 0.01) and immobilized with gallamine triethiodide (flaxedil, 2 mg/kg body weight). A portion of the brain was exposed by means of a dental drill; a platinum coated stainless steel electrode (Transidyne General) was inserted in the olfactory bulb. EEG responses evoked by test samples were amplified with a Bioelectric Instruments (model DS2c) and recorded on a Hewlett Packard model 7712B oscillagraph. Figure 1 presents a typical recorder trace showing the background and stimulus response. A second channel of the oscillagraph was equipped with an integrating preamplifier, so that the integration of the EEG could be recorded. The integrator sums the voltages in the positive part of the wave form. The slope of the line obtained from the integrator can be used to quantify the EEG records. To standardize the response, the slope of the integration of a response to each sample was divided by the slope of the integration of the response to home-

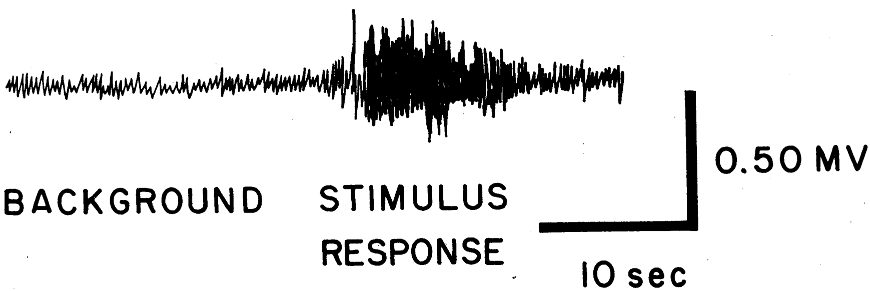

FIGURE 1. Example of electroencephalographic output (hand wash).

stream water. An F-test was used to test the significance of the responses. Each sample was introduced in a random order one time each trial. Trials were repeated 4 times. Algoma city tap water was used to rinse the nares between trials.

Water samples from the homestream were fractionated in a variety of ways. Factors considered were: the variability of the response of a fish to a given sample and the pH, molecular weight, and volatility of the sample. Additional studies on the chemical nature of the homestream dealing with carbon filtration, dialysis, and Sephadex chromotography were not conclusive and will not be reported here. Experiments with the ionic strength and concentration of the homestream water will not be reported for the same reason. For further details consult Cooper (1971).

In the first experiment, two samples of stream water, one taken directly from the stream and one stored at 5 C for one day, were used to test two fish for their variability in response.

In the second experiment, a group of samples of different pH were prepared by adding sodium bicarbonate (0.01M) to Algoma city tap water and adjusting the pH of the solutions with sulfuric acid or sodium hydroxide, as needed, to pH 5, 6, 7, 8, and 9. One fish was used in this experiment.

In a third experiment, homestream water was filtered through a glass fiber filter and 0.45 micron and 0.22 micron pore size Millipore filters. Four fish were used in this experiment.

Finally, in a fourth experiment, homestream water was fractionated by means of a vacuum distillation apparatus at 6 mm Hg pressure at 20 C. This equipment consisted of a Snyder-ball column and a water-jacketed condensor. A thermometer was positioned at the top of the column to observe the temperature of the distillate. A dry ice acetone bath was used to trap the distillate. It took 3.5 hours to reduce 750 ml to 250 ml under these conditions. Two fish for each of 2 distillations were used in this experiment.

For the experiments reported here, a total of 10 fish and 15 water samples were used.

RESULTS

The results of the first experiment (Figure 2 and Table 1) indicate that the variability in fish response as reflected in the standard deviation was roughly 25%. Data from different animals cannot be compared directly, i.e. the data from coho 144 and 146 cannot be pooled, although the ranking for samples for each fish can be compared.

In the second experiment, filtration through glass fiber filter, 0.45 micron or 0.22 micron pore size Millipore filters did not seem

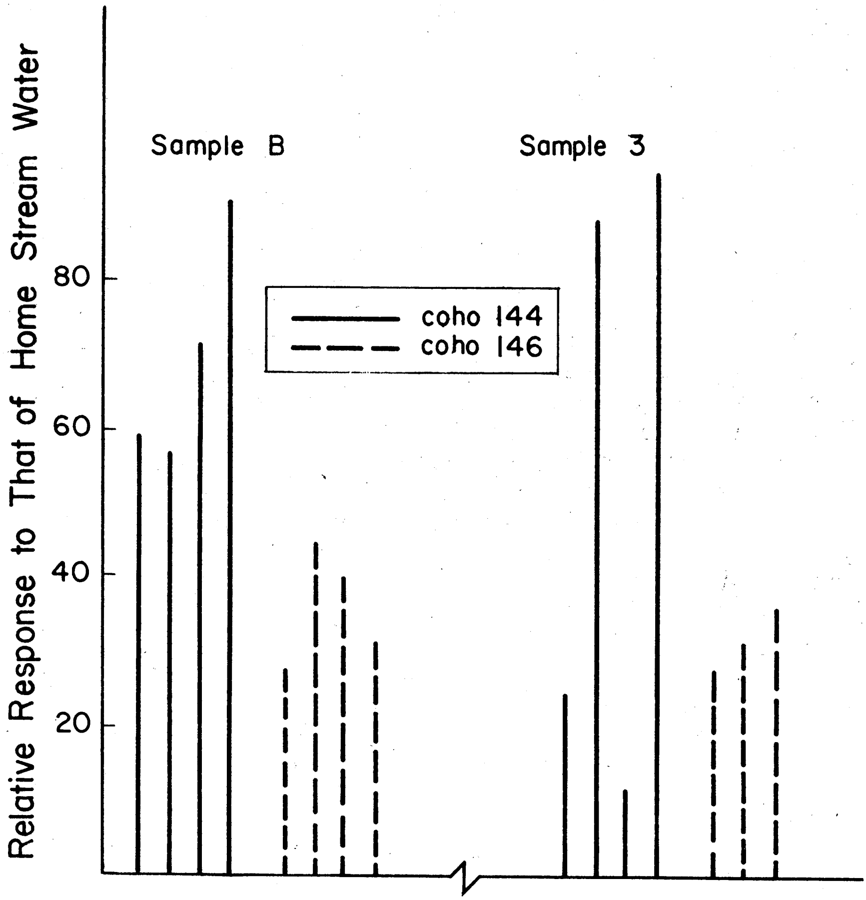

FIGURE 2. Replicates of raw stream water (B) and water stored for one day at 5 C (3).

TABLE 1. REPLICATE SAMPLES OF RAW STREAM WATER AND STREAM WATER STORED AT 5 C

(Mean and standard deviation of the integration of response to the stimuli expressed as the per cent of the integration of the response of a reference sample of stream water.)

	Raw	Sample 5 C
Coho 144	66 ± 9	50 ± 25
Coho 146	46 ± 10	32 ± 4

to affect the samples. The amplitude of responses to these samples was roughly the same before or after filtration (Table 2).

The salmon responded most strongly to acid pH (4 and 5). They responded less strongly to basic pH (8 and 9) than to neutral pH (7) (Figure 3).

In the fourth experiment, it is clear that there is a higher amplitude response to the non-volatile portion than to the volatile portion of the water distilled at 20 C (Table 3).

TABLE 2. EEG RESPONSES TO WATER FILTERED THROUGH GLASS FIBER FILTER, 0.45 AND 0.22 MICRON PORE SIZE MILLIPORE FILTERS

	Coho	Coho	Coho	Coho
Water	144	146	147	150
Homestream	69 ± 20	36 ± 11	37 ± 6	80 ± 14
Glass fiber	65 ± 30	31 ± 24	17 ± 1	141 ± 51
0.45 μ	80 ± 50	—	7 ± 7	88 ± 15
0.22 μ	80 ± 50	55 ± 25	36 ± 20	80 ± 12

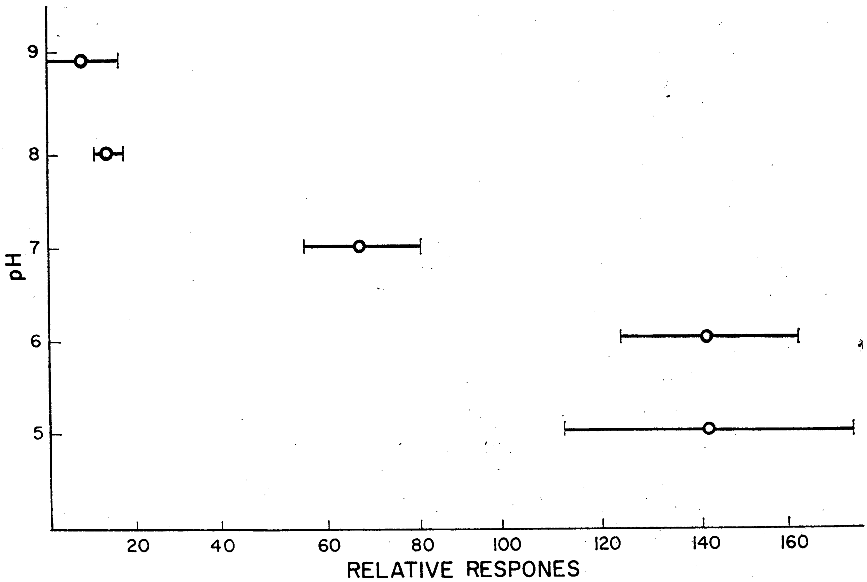

FIGURE 3. EEG response to homestream water adjusted to pH, 5, 6, 7, 8, and 9 (mean and standard deviation).

TABLE 3. VACUUM DISTILLATION OF HOMESTREAM WATER. DUPLICATE RUNS ON EACH FISH FOR TWO SETS OF DISTILLATION SAMPLES

(Mean and standard deviation of the integration of the response to the stimuli expressed as the per cent of the integration of the response of a reference sample of stream water.)

	Samples			
	Distillate 1	Residue 1	Distillate 2	Residue 2
Coho 131	58 ± 25	97 ± 11	—	—
Coho 132	30 ± 3	70 ± 1	—	—
Coho 144	—	—	23 ± 15	114 ± 47
Coho 146	—	—	0 ± 0	47 ± 12

DISCUSSION

One problem in interpreting the data is that one cannot make inter-fish comparison. This may be due to difference in handling of the fish. Coho salmon were taken out of the trap at one time on the day of the experiment. It is possible that fish had been in the trap for different lengths of time for a few minutes to several days. Ueda *et al.* (1967) have pointed out that fish kept in a holding tank for a week became unresponsive to their homestream water; this may be due to an advance stage of sexual "Ripening" (as Fagerlund *et al.*, 1963 suggests) or a gradual acclimation of the fish to the homestream water odor.

The results of the third experiment show that the homestream odor has a molecular weight under one million, the approximate size of material retained on a 0.22 micron pore size Millipore filter. Since none of these filters seems to add an odor to the homestream (or subtract one from the water), they are a useful technique for cleaning up the extraneous matter in the water; there was a large quantity of material left on the filters after the experiments. The final experimental results indicate that the stimulatory portion of the water is non-volatile at 20 C, since there is a higher response to the residue than to the distillate.

The second and fourth experiments mentioned above leave little doubt that the EEG technique can be used to detect difference in water samples; it is possible to determine whether the character of the water sample has been changed by the experimental procedures. However, since the standard deviation in response is quite large, the technique may not be useful in detecting subtle differences between samples.

A second underlying problem that may limit the usefulness of the EEG technique, is that it is not possible to distinguish between two kinds of responses from the fish. A sample that represents a danger or avoidance reaction, such as handwash (a sample in which the hand has been dipped) will give the same amplitude response, as far as one can tell from the EEG, as a sample that is stimulatory, such as the homestream water. Therefore, it is impossible to tell whether the distillation experiment, for instance, produced residues important in homing or whether merely concentrated "avoidance" fractions were formed. Indeed, the stimulatory fractions observed with the EEG technique may not be related in any simple manner to either the stimulatory fraction found in behavioral work or those fractions actually necessary for homing. Perhaps in the future, any experimental results obtained with the EEG technique should be confirmed with a behavioral bioassay.

Until these problems are overcome, any future work that attempts to utilize the EEG to determine homestream constituents may be of limited value.

ACKNOWLEDGEMENT

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STUDIES ON THE Ca, Mg, AND Sr CONTENT OF FRESHWATER CLAMSHELLS

G. Fred Lee
University Texas—Dallas
and
William Wilson
University Wisconsin—Madison

ABSTRACT

The relationship of Ca, Mg and Sr in Lakes Mendota, Fox and Trout in Wisconsin and clamshells collected from these lakes shows a negative correlation between shell and water Sr/Ca ratio. The Mg/Ca ratio showed considerable scatter and in general a direct relationship between shell composition and water composition.

INTRODUCTION

As part of a study on the feasibility of using the Ca, Mg and Sr content of freshwater clamshells as indicators of paleohydrologic conditions, it was necessary to investigate the relationship of freshwater clamshell and water composition. Since river and stream chemical composition varies with discharge, it was decided to use lake clams, since the water composition should be relatively constant. A literature review on the relationship between clamshell and water composition has been presented by Lee and Wilson (1969).

EXPERIMENTAL PROCEDURE

The Ca, Mg and Sr contents of lake water and clamshells were determined by atomic absorption spectrophotometry according to the procedure described by Lee and Wilson (1969). The clams were taken alive by wading along the beach in waist-deep water. The shells were cut into sections and ashed to separate into laminar layers. Only the laminar layers were analyzed. Except as noted, the laminar layers were analyzed as a group.

RESULTS

A preliminary phase of this study was concerned with the determination of the variability of the calcium content of lake clams. This was undertaken because there was no information on their chemical components, as all previous work has been concerned with specimens found in rivers, streams and marine environments (Nelson, 1963, 1967; Odum, 1957; Thompson and Chow, 1955). Sixteen clams of the same species *(Lampsilis siliquoidea rosacea)* were collected live from Lake Mendota. The laminar layers of each of the shells were analyzed for their calcium content. The sample had a mean and standard deviation calcium content per gram of shell weight of 409 ± 6 mg/g. As with other aragonite shells, lake clamshells are principally calcium carbonate with the addition of trace elements.

The total sample of lake clams (N = 75) yields a mean and standard deviation of 413 ± 10 mg Ca/g of shell weight. When this is compared with a series of river clams analyzed by Nelson (1963), where 23 clams had a mean and standard deviation of 400 ± 1.4 mg Ca/g of shell, the difference between the means is statistically significant (calculated t = 10.8 with 109 degrees of freedom). Further, Nelson (1963) compared the means of river clams with the data of Thompson and Chow (1955) on 64 marine shells, which had a mean and standard deviation of 392 ± 1.2 mg Ca/g of shell. This gave a statistically significant t of 4.3 with 85 degrees of freedom. The differences between lake, river and marine shells (in a system that is almost pure calcium carbonate) would suggest that the environment is an important factor in the secretion of elements within the clamshell. Therefore, the clams of 1 species from 1 lake appear to have an essentially constant calcium concentration. However, the data have indicated that clams may vary according to their environmental situation. Because of this variability, calcium analyses have been included for every sample. This procedure insures a more accurate measurement of the ratios of calcium with other cations.

Studies were conducted to examine the variability of shell among lake clams. A live clam *(Lampsilis siliquoidea rosacea)* was taken from Lake Mendota; its shell after ashing was separated into areas shown in Fig. 1. The morphological parts were analyzed separately. Examination of the results, as presented in Table 1, shows that differences occur between layers within each part of the shell. For example, the Sections 3–7 (laminar layers) have a mean and standard deviation Ca, Mg and Sr concentration of 406 ± 15 mg/g, 59 ± 15 μg/g and 146 ± 17 μg/g, respectively. Differences occur between parts of the shell. The peripheral layers (Sections 9–14) contain about 70% as much Sr as Sections 3–7. This variability found in lake clams in both concentration and atomic ratios was similar to that reported by Nelson (1964) for river clamshells.

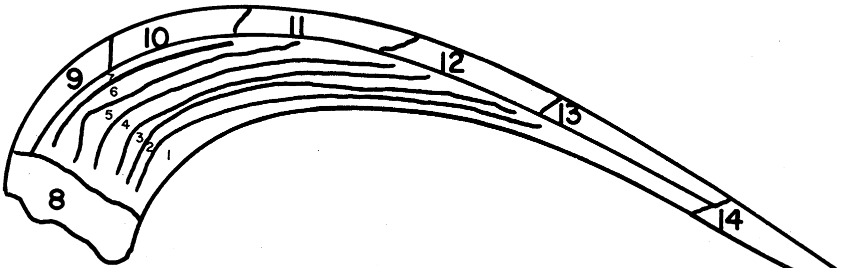

FIGURE 1. Cross section of clamshell analyzed. Sections 1–7 were the laminar layers from inside toward outside.

The laminar layers are secreted as annual growth layers. The peripheral layers are often damaged, encrusted with foreign matter, and the parts near the umbo usually show signs of abrasion and wear. Because of the large differences found between various morphological parts of the shells, all further analyses have been confined to the laminar layers. These layers shown in Fig. 1 as Sections 3–7 represent that part of the shell least likely to be affected by post-depositional factors and, therefore, would most closely reflect the living clam's chemical milieu at the time of deposition of each laminar layer.

Two shells *(Lampsilis siliquoidea)*, from each of 3 Wisconsin lakes, were collected to examine the composition of the laminar layers in a multiple sample and from different environments. The specimens were separated into laminar layers and analyzed for Ca, Mg and Sr content. The data in Table 2 show that the laminar layers of the clams from each lake have marked differences in

TABLE 1. COMPOSITION OF LAKE MENDOTA CLAMSHELL
(Lampsilis siliquoidea rosacea)

Section	Composition			Atom Ratios	
	Ca (mg/g)	Mg (μg/g)	Sr (μg/g)	Sr/Ca x10⁶	Mg/Ca x10⁶
1	573	--	211	168	---
2	468	70	162	158	246
3	421	41	172	187	160
4	393	44	155	180	185
5	426	64	137	147	248
6	391	80	120	140	338
7	397	67	144	166	279
8	407	83	133	149	337
9	406	35	96	108	142
10	395	22	95	110	92
11	403	44	72	82	180
12	386	27	86	102	115
13	400	34	82	94	140
14	398	24	81	93	99

TABLE 2. CONCENTRATION OF CALCIUM, MAGNESIUM AND STRONTIUM IN THE LAMINAR LAYERS OF LAKE CLAMSHELLS
Lampsilis siliquoidea

Lake	Clam	Layer	Concentration			Atom Ratios	
			Ca (mg/g)	Sr (μg/g)	Mg (μg/g)	Sr/Ca x10⁶	Mg/Ca x10⁶
Beaver	I	1	389	111	59	130	250
		2	388	105	96	124	408
		3	392	131	61	153	257
		4	409	138	57	154	230
	II	1	358	104	74	133	341
		2	391	137	102	160	431
		3	396	145	93	167	387
		4	371	175	60	216	267
		5	383	216	48	258	207
Nashota	I	1	395	61	41	70	171
		2	396	130	58	150	242
		3	398	90	51	103	211
		4	393	151	50	176	210
	II	1	392	63	55	74	232
		2	388	60	27	71	115
		3	378	132	69	159	301
Booth	I	1	444	33	67	34	249
		2	451	99	63	100	230
	II	1	414	55	62	61	247
		2	440	82	101	85	379
		3	435	65	70	68	265

composition. This variability displays the typical heterogeneous distribution of trace elements in mollusks. Even in this very small sample, there appear to be differences in the atomic ratios from one lake to the next, although the samples are too small for comparative purposes.

The variability found in this study is like that mentioned previously (Curtis and Krinsley, 1965), where a large number of samples must be studied to define any relationship between shell and water composition. Similar conclusions must be reached as a result of this study. A large number of clams of 1 genus and preferably of 1 species must be analyzed from a number of lakes of differing composition before a relationship can be defined.

Inasmuch as the nature of this work is concerned with the mean chemical composition of groups of clams in relationship to their environment, all further analyses were conducted on all the laminar layers as a whole. The pretreatment of the shell was modified, such that after ashing the laminar layers were separated from the other parts of the shell. The layers were then dissolved as a group in HCl and analyzed.

Three Wisconsin lakes were utilized in this study on the basis of the availability of clamshells and water samples. In this group there are 2 hard-water lakes (Fox and Mendota) and 1 soft-water lake (Trout). A total of 29 clamshells from Trout Lake, 30 from Fox Lake and 16 from Lake Mendota, all of the species *Lampsilis siliquoidea,* have been analyzed for Ca, Mg and Sr. The water ratios are represented by the median summer values. Although large amounts of data are available for Lake Mendota water composition, only the summer values were available for Fox and Trout Lakes. These values are more closely comparable for the purposes of this study and also coincide with the expected period of maximum growth of the clams in these lakes.

The Sr/Ca ratio of clamshells versus water, as shown in Fig. 2, demonstrates a strong negative correlation, with a correlation coefficient (r) of —0.83.

The Sr to Ca atomic ratio in shells is constrained because all shells contain essentially constant amounts of calcium. It should be pointed out that the mean Sr/g of shell increases with increasing hardness of the water. Even though Dodd (1965) demonstrated a temperature dependence for Sr in marine pelecypods, this does not appear to be a factor for freshwater clamshells used in this

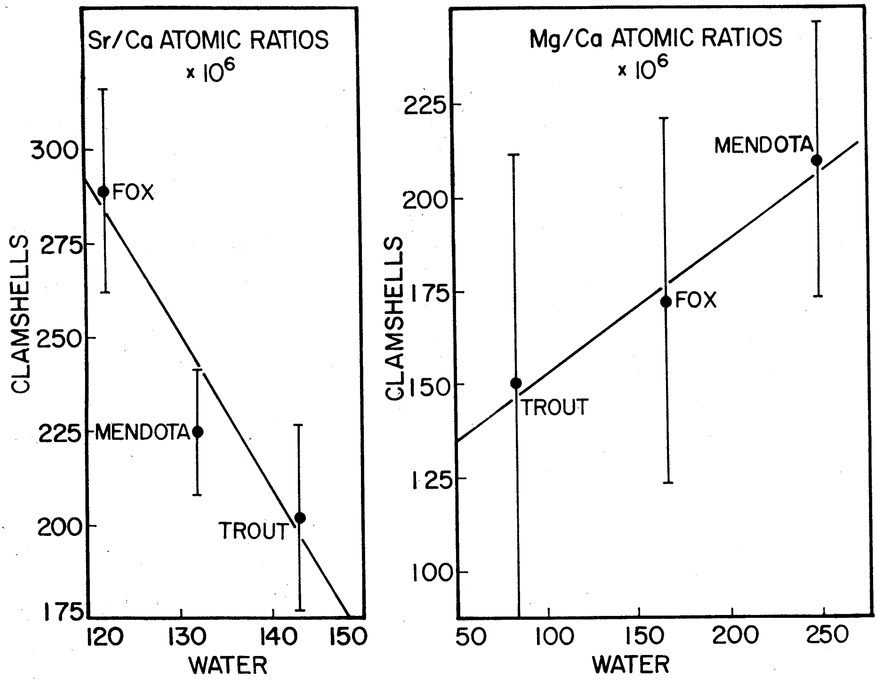

FIGURE 2. Relationship of atom ratios of lake clamshell and water composition. Mean and standard deviation indicated by point and bar.

study. The temperature regimes for Fox Lake and Lake Mendota are approximately the same; while Trout Lake, located in northern Wisconsin, is about 2°C cooler. Therefore, the atomic ratio of Sr/Ca in these freshwater clamshells is dependent upon the elemental composition of its environment.

The Mg/Ca atomic ratio of clamshells versus water shows a weak positive correlation coefficient (r) of 0.4. This is the result of large variances within each sample and is consistent with the results obtained from the archaeological sites studied by Lee and Wilson (1969). It is not clear why there should be such a high degree of variability within a single species in a relatively constant environment.

DISCUSSION

Clams are integrators of their environment. The chemical composition of the shell should reflect the chemical composition of the water. Yet, this study has shown that for the three lakes examined there is an inverse relationship between the Sr/Ca ratio in the lake water and in the laminar layers of a clamshell. Part of this variability is due to the vital effects of the clam. The study of the single Lake Mendota clam where the shell was sectioned into various parts showed that there was almost as much variability between parts in a single shell as was found between shells taken from a beach in a single lake or shells taken from different lakes. It is clear that the simple chemical composition of the water does not control shell composition. Other factors must also have an important function in determining the small differences observed in shell composition. Some of the variability may be due to the water itself. Although a lake is, in general, a fairly homogeneous chemical system, it must be pointed out that the near-shore environment is the zone of great biochemical activity and its composition is much more subject to change than the open water in most lakes. The clam's immediate environment is often very complex because of the active photosynthesis and respiration taking place. Many of the clams collected from Lake Mendota and other lakes have thick growths of the alga *Cladophora* attached to them. The water taken in by the clam must pass through or near this algal mat. During periods of light, $CaCO_3$ precipitation is likely in hard-water lakes due to the photosynthesic pH increase. Some of the clams taken from some lakes had 1–2 mm thick layers of precipitated $CaCO_3$ on the outside of the shell. In the dark the pH of the clam's intake water should drop significantly due to the respiration of the attached algae, recycled clam outlet water and the respiration of microorganisms working on the detritus that accumulates on the bottom in the vicinity of the clam. While collecting the clams in Lake Mendota, it was noted that they often could be located by finding the wave-sorted detritus arising from dead leaves, twigs, etc. The reduced pH that results from respiration of organisms would be expected to cause solution of $CaCO_3$ precipitates. In addition to obtaining the Ca, Mg and Sr from the water, the clam also may take in particulate $CaCO_3$ that arises from photosynthetic precipitation as described above and detrital $CaCO_3$ arising from parts of other organisms. This particulate $CaCO_3$ could be dissolved and later incorporated in the shell.

Although few studies have been conducted on the chemical characteristics of the near-shore environment of lakes, it might be suspected that it would show not only diurnal and seasonal changes but also annual changes due to difference in the amounts of macrophytes and attached algae. Evidently, based on the marked variability of the chemical composition of annual layers of the clamshells, it must be concluded that the clam is responding to these changes. There is no single relationship between water and shell composition and any study of the relationship must involve large numbers of samples and detailed studies of the clam's microenvironment.

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HYDROLOGY AND TROUT POPULATIONS OF COLD WATER RIVERS OF MICHIGAN AND WISCONSIN[1]

G. E. Hendrickson
*U. S. Geological Survey—
Madison, Wis.*
and
R. L. Knutilla
*U. S. Geological Survey—
Okemos, Mich.*

ABSTRACT

Statistical multiple-regression analyses showed significant relationships between trout populations and hydrologic parameters. Parameters showing the higher levels of significance were temperature, hardness of water, percentage of gravel bottom, percentage of bottom vegetation, variability of streamflow, and discharge per unit drainage area. Trout populations increase with lower levels of annual maximum water temperatures, with increase in water hardness, and with increase in percentage of gravel and bottom vegetation. Trout populations also increase with decrease in variability of streamflow, and with increase in discharge per unit drainage area. Most hydrologic parameters were significant when evaluated collectively, but no parameter, by itself, showed a high degree of correlation with trout populations in regression analyses that included all the streams sampled. Regression analyses of stream segments that were restricted to certain limits of hardness, temperature, or percentage of gravel bottom showed improvements in correlation. Analyses of trout populations, in pounds per acre and pounds per mile and hydrologic parameters resulted in regression equations from which trout populations could be estimated with standard errors of 89 and 84 per cent, respectively.

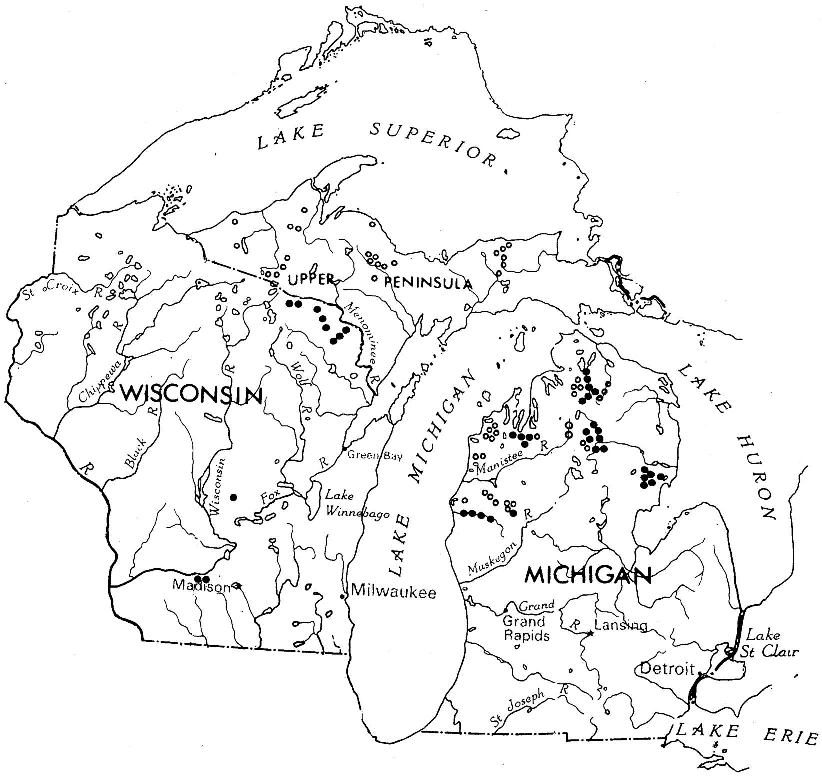
INTRODUCTION

Trout populations in rivers respond to a variety of environmental factors, most of which are related to the hydrology of the streams in which they live. In 1970, a preliminary analysis of hydrologic parameters and trout populations for 16 stream segments in Michigan showed a negative relationship between mean annual maximum water temperatures and trout populations (Hendrickson and Doonan, 1971). A negative relationship between

[1] Publication authorized by the Director, U.S. Geological Survey.

the variability of streamflow and trout populations also was suggested.

The present study, covering a larger area of Michigan and Wisconsin, was designed to analyze in greater detail hydrologic factors that might influence trout populations. The study was also designed to determine, if possible, the relative importance of each hydrologic parameter on the populations. Hydrologic data were determined for 112 stream segments in Michigan and Wisconsin for which trout population data were available. Eighty-eight of these segments (Fig. 1) were used to test for possible relationships between trout populations and hydrologic parameters. Selection of the 88 segments was based entirely on accuracy and completeness of hydrologic data. For those streams on which data were available for many segments, some segments, generally alternate segments,



EXPLANATION

● Trout populations estimated by mark-and-recapture.

○ Trout populations estimated by single survey.

FIGURE 1. Location of stream segments included in sampling.

were omitted from the analysis to avoid over-emphasis of any particular stream.

HYDROLOGIC PARAMETERS

Hydrologic parameters that were used in this study describe the character of a stream's channel, bed, and banks, its streamflow characteristics, and the quality of its water. Most of the data on channel character were obtained by field mapping during the summer of 1971. Data on streamflow were obtained from records for stream gaging stations operated by the U.S. Geological Survey and from discharge measurements that were available or were made at the time of channel mapping. Data on water quality were obtained from records of State agencies, the U.S. Geological Survey, and from field analyses made at each stream segment.

Channel Character. Each stream segment was surveyed to determine its average width, depth, and surface area; the type of bed materials, as percentages of gravel, sand, or muck; and the percentage of the stream bottom that had submerged vegetation. Also determined were the average bank height, bank material, and bank vegetation as percentage of hardwoods, conifers, brush, or grass. Finally the percentage of the stream bottom which would afford cover for trout, such as undercut banks, logs, boulders, and overhanging brush was visually estimated.

Average gradients of the stream segments were determined from topographic maps. Each reported gradient is the average computed between topographic contours that cross the stream above and below the measured stream segment. The actual gradient of the segment may be higher or lower than the value so obtained.

Streamflow. For each stream segment the average discharge, in cubic feet per second and cubic feet per second per square mile, and parameters of low flow and flow duration were determined. As an index of low flow, the median annual 7-day flow (7-day Q_2) was used. Flow-duration data included the discharges equaled or exceeded for 10 and 90 per cent of the time.

Characteristics of streamflow were determined from streamflow records at gaging stations or by correlating discharge measurements made at each stream segment with records for gaging stations. Because most discharge measurements were made when streams were at base flow, estimates of low-flow parameters (median minimum 7-day Q_2 and 90 per cent duration) are more reliable than those of high flow (10 per cent duration). Accuracy of streamflow parameters also varies with the number of streamflow measurements available at each stream segment and with the degree of correlation of the measurements with data for gaging stations. The low-flow parameters for most stream segments probably are accurate to about 20%. High-flow parameters probably are accurate to about 30%.

The ratio of 10 per cent and 90 per cent duration discharges was used as an index of the variability of streamflow. As an index of the velocity of each stream segment, the median minimum 7-day discharge was divided by the cross-sectional area of the segment. The cross-sectional area, computed as the product of the average width and average mid-channel depth, is greater than the actual area, because the mid-channel depth usually is greater than the average depth in the cross-section. Accordingly, the average velocities tabulated are low. However, velocities are representative and are believed to be comparable between streams.

Quality of Water. Because temperature was shown to be one of the more significant water-quality parameters in the 1970 study, greater effort was made to obtain temperature data than other water-quality data. Thermometers that register maximum and minimum temperatures were installed in each of the stream segments mapped, unless adequate temperature records were already available at the site. Records of maximum and minimum temperatures were obtained for at least one summer month at almost all sites. These records were correlated with temperature records at gaging stations to obtain the mean annual maximum and mean July temperatures. For most sites these temperatures are probably accurate within 3 F.

Specific conductance, pH, and hardness of water were determined in the field during the summer of 1971, usually during base-flow conditions. Values of specific conductance probably are accurate within about 10 micromhos; values of pH probably are accurate to one-half pH units; and values of hardness probably are accurate to about 20 milligrams per liter. Appearance of the water (clear, colored, or turbid) was recorded, but numbers were not assigned to these parameters and they were not included in this analysis.

Another important water-quality characteristic is dissolved oxygen. One field analysis of dissolved oxygen was made at most stream segments. However, because of diurnal variation in dissolved oxygen, all values are not representative of the dissolved oxygen content for each stream segment. Consequently, values of dissolved oxygen were not used in the regression analysis.

TROUT POPULATION PARAMETERS

Trout population data were obtained from State fisheries agencies in Michigan and Wisconsin. The accuracy of these data varies widely because the purpose and method of inventory vary. Estimates of trout in 39 stream segments were obtained by the "mark and recapture" method. The accuracy of the results on these segments is believed to be within about 30%. Estimates of trout populations for other segments were obtained from one or more stream surveys. The error in estimating these populations may be 50% or more. However, it is believed that the errors are random, and that the population estimates are not consistently higher or lower than those obtained by "mark and recapture" survey.

All trout population surveys used in this study were made in late summer or early fall. Some of the streams sampled receive annual plantings of trout. No attempt was made to exclude hatchery trout in the population estimates. However, large trout that were obviously migratory spawners were excluded. Population data were defined as number per acre, pounds per acre, number per mile, pounds per mile, and pounds per acre foot.

RESULTS OF STATISTICAL ANALYSES

Statistical multiple-regression analyses were used to develop relationships between trout populations and hydrologic parameters. The analyses provided a mathematical equation of the relation between trout populations and selected hydrologic parameters. The analyses also provided a measure of the accuracy of the defined relationships and the level of significance of each hydrologic parameter in the relation.

Trout populations were correlated with hydrologic parameters of channel character, fish cover, streamflow characteristics, and water quality. For each combination of variables tested, the regression equation, multiple correlation coefficient, standard error of estimate, and the significance of each independent variable were calculated. Calculations were then repeated, eliminating the least significant hydrologic parameter each time, until only the most significant parameter remained. The procedure was repeated for many combinations of hydrologic parameters and trout populations.

In the analyses it was assumed that the hydrologic parameters were logarithmically related to trout populations in the linear format. In each case this may not be entirely true. For example, Benson (1953) has shown that the condition and growth of brook trout in the Pigeon River (Michigan) were best when water temperatures ranged from 55 to 66 F. Also, as this and other studies have shown, trout populations tend to increase as hardness and specific conductance of water increase. However, it appears unlikely that high levels of hardness or specific conductance would be increasingly favorable to trout populations. Other hydrologic parameters also may have favorable ranges not yet demonstrated. It is believed that any deviation from the straight-line relationship does not seriously affect the results of this study. Graphic plots of trout populations and independent variable did not reveal any divergency from the straight-line relationship. The probable reason for this is that values for most parameters are within the favorable range for trout. Also, values of many of the parameters evaluated in the study affect trout populations in only one direction from the favorable limits. For example, few of the streams sampled are too cold in summer for maximum production of trout. Again, it is unlikely that any of the streams sampled have hardness or specific conductance greater than the optimum range for trout.

A summary of the hydrologic and trout population parameters for which data were obtained are listed in Table 1. Shown in the table are the degree of correlation between each of the parameters. This simple correlation matrix was used to aid in selecting independent variables—variables that did not exhibit a high degree of intercorrelation or interdependence—for regression analysis. For example, specific conductance and hardness were not used in the same regression analysis because of their high degree of correlation (0.97). Table 1 also shows the degree of correlation between the dependent variables (last five rows) and each of the independent variables. None of the independent variables, by itself, shows a high degree of correlation with trout populations for the units of population shown. The relation between pH and trout, in pounds per mile, has the highest degree of correlation (0.47).

Analyses of trout populations in pounds per acre and pounds per mile resulted in regression equations from which trout populations could be estimated with approximately the same standard error (89 and 84%, respectively). The equations that provide the best relations, and for which independent basin parameters are effective within 90-per cent confidence, are shown in Table 2. Analyses of trout populations in pounds per acre-foot, number per acre, and number per mile with several combinations of independent variables showed no strong correlation. In the analyses, the standard error of estimate was generally in excess of 110% (Table 2).

To test the defined relationships for possible areal differences, the difference between observed and computed values, termed residuals, were calculated for each station analyzed. An analysis of the residuals showed that the regression equations were unbiased areally. Reaches of some streams, and small local areas, showed some differences or bias, but they were too small to warrant separate analysis.

TABLE 1. SIMPLE CORRELATION COEFFICIENTS FOR HYDROLOGIC AND TROUT POPULATION PARAMETERS

	Area (acres)	Width (ft)	Depth (ft)	Gravel (%)	Sand (%)	Muck (%)	Bottom vege-tation (%)	Cover (%)	Bank height (ft)	Hard-wood (%)	Coni-fer (%)	Brush (%)	Grass (%)	Drain-age area (sq. mi.)	Mean dis-charge (cfs)	Mean dis-charge (cfsm)
Area	1.00															
Width	.43	1.00														
Depth	.29	.54	1.00													
Gravel	.30	.27	.04	1.00												
Sand	-.17	-.17	.24	-.62	1.00											
Muck	-.06	-.17	.01	-.26	.10	1.00										
Bottom vegetation	.07	.23	.31	-.19	.13	.38	1.00									
Cover	-.16	-.30	.12	-.21	.33	.19	.27	1.00								
Bank height	.13	.01	-.17	.12	-.14	-.39	-.23	-.30	1.00							
Hardwood	.19	.22	.10	.44	-.17	-.28	-.15	-.16	.37	1.00						
Conifer	.20	.33	-.07	.11	-.10	-.12	-.13	-.07	.20	.08	1.00					
Brush	-.01	-.15	.11	.08	-.02	.27	.10	.09	-.58	-.29	-.47	1.00				
Grass	.18	.29	.24	-.07	-.04	.18	.16	-.11	-.02	-.19	-.01	-.12	1.00			
Drainage area	.39	.84	.66	.42	-.25	-.31	.18	-.20	-.01	.29	.12	.05	.18	1.00		
Mean Q (cfs)	.36	.85	.65	.34	-.14	-.40	.05	-.21	-.04	.19	.16	-.02	.23	.93	1.00	
Mean Q (cfsm)	-.17	-.17	-.17	-.30	.33	-.15	-.35	.03	-.09	-.32	.07	-.18	.08	-.42	-.06	1.00
7-day Q2 (cfsm)	.05	.08	.14	-.10	.34	-.03	-.08	.25	-.30	-.08	.17	-.04	.07	-.14	.12	.66
10% (cfsm)	-.26	-.20	-.26	-.33	.26	-.18	-.40	-.10	.03	-.35	.02	-.19	.06	-.42	-.09	.91
90% (cfsm)	.04	.07	.12	-.10	.33	-.05	-.12	.24	-.29	-.10	.18	-.06	.07	-.15	.13	.71
10/90	-.26	-.24	-.33	-.18	-.10	-.11	-.22	-.31	.29	-.20	-.15	-.10	-.02	-.21	-.19	.10
Mean Q/7-day Q2	-.24	-.28	-.36	-.17	-.11	-.10	-.25	-.31	.30	-.22	-.16	-.13	-.02	-.25	-.21	.15
Velocity	.21	.42	.27	.39	-.15	-.40	-.10	-.02	-.18	.21	.06	.13	.05	.58	.65	.04
W/D	.27	.76	-.13	.28	-.38	-.21	.03	-.44	.14	.18	.45	-.26	.15	.48	.50	-.07
Slope	-.28	-.50	-.63	-.05	-.15	-.12	-.29	.09	.18	-.03	.12	-.15	-.27	-.56	-.53	.23
Max. temp.	.12	.30	-.05	.18	-.28	.12	.12	-.24	.04	.24	-.01	-.19	.03	.24	.16	-.26
July temp.	.15	.33	-.02	.20	-.26	.10	.19	-.17	.10	.23	-.02	-.18	.04	.31	.19	-.38
Spec. cond.	.36	.13	.23	.17	-.07	.28	.24	.13	-.33	.12	.04	.16	.07	.20	.12	-.22
Hardness	.34	.12	.26	.18	-.04	.24	.22	.20	-.33	.16	.03	.17	.03	.20	.13	-.21
pH	.27	.39	.39	.20	-.04	-.12	.25	.10	-.01	.38	.14	-.18	-.04	.44	.38	-.25
TROUT POPULATIONS																
lbs/acre	-.02	-.14	-.04	.12	-.02	.03	.13	.29	-.27	.01	-.08	.11	-.08	-.09	-.11	-.03
lbs/ac-ft	-.01	-.29	-.34	.14	-.13	.02	-.02	.19	-.18	-.06	-.07	.09	-.13	-.29	-.29	.06
lbs/mile	.16	.32	.26	.22	-.09	-.06	.22	.17	-.26	.08	.11	.03	.04	.32	.32	-.06
No./mile	.10	.17	-.04	.23	-.16	-.06	-.06	.02	-.15	-.11	.14	.09	.13	.10	.13	.07
No./acre	-.07	-.24	-.29	.10	-.08	.04	-.13	.13	-.15	-.17	-.02	.15	.01	-.27	-.25	.12

TABLE 1. (CONTINUED)

	7-day[1/] Q2 (cfsm)	10%[2/] dura-tion dis-charge (cfsm)	90%[3/] dura-tion dis-charge (cfsm)	Ratio 10/90	Ratio mean dis-charge to 7-day Q_2	Veloc-ity index	Width depth ratio	Slope (ft/ mile)	Average annual maximum temper-ature (°F)	Average annual July temper-ature (°F)	Specific conduct-ance (micro-mhos	Hard-ness (mg/1)	pH (units)	Trout population lbs/ acre	lbs/ ac-ft	lbs/ mile	No./ mile	No./ acre
Area																		
Width																		
Depth																		
Gravel																		
Sand																		
Muck																		
Bottom vegetation																		
Cover																		
Bank height																		
Hardwood																		
Conifer																		
Brush																		
Grass																		
Drainage area																		
Mean Q (cfs)																		
Mean Q (cfsm)																		
7-day Q_2 (cfsm)	1.00																	
10% (cfsm)	.32	1.00																
90% (cfsm)	.99	.38	1.00															
10/90	-.67	.49	-.63	1.00														
Mean Q/7-day Q_2	-.65	.50	-.59	.98	1.00													
Velocity	.44	-.15	.44	-.54	-.54	1.00												
W/D	-.01	-.03	-.01	-.03	-.06	.29	1.00											
Slope	.04	.23	.05	.15	.18	-.22	-.10	1.00										
Max. temp.	-.32	-.16	-.30	.15	.16	-.06	.39	-.30	1.00									
July temp.	-.39	-.26	-.38	.14	.13	-.05	.40	-.30	.93	1.00								
Spec. cond.	.29	-.47	.27	-.65	-.61	-.35	-.03	-.16	.01	-.01	1.00							
Hardness	.34	-.48	.32	-.70	-.66	.41	-.06	-.15	-.01	-.01	.97	1.00						
pH	.27	-.43	.24	-.59	-.61	.49	.16	-.23	.13	.19	.57	.61	1.00					
TROUT POPULATIONS: lbs acre	.22	-.17	.21	-.34	-.31	.12	-.14	.14	-.34	-.33	.35	.35	.32	1.00				
lbs/ac-ft	.18	-.05	.19	-.21	-.18	.05	-.08	.32	-.23	-.23	.28	.27	.18	.89	1.00			
lbs/mile	.29	-.22	.28	-.45	-.44	.36	.17	-.12	-.23	-.20	.41	.41	.47	.87	.69	1.00		
No./mile	.21	-.01	.21	-.21	-.21	.18	.23	.18	-.32	-.27	.19	.15	.16	.66	.66	.68	1.00	
No./acre	.16	.05	.16	-.11	-.10	-.02	-.06	.40	-.41	-.38	.13	.10	.01	.73	.78	.52	.90	1.00

1/Average 7-day low flow for 2-year recurrence interval.
2/Discharge equaled or exceeded 10 percent of the time.
3/Discharge equaled or exceeded 90 percent of the time.

TABLE 2. SUMMARY OF REGRESSION RELATIONS

$$Y = aG^{b1}BV^{b2}Q^{-b3}Q_2^{b4}DR^{b5}V^{b6}WD^{b7}T^{b8}H^{b9}T_2^{b10}$$

Trout population	Regression constant	Regression coefficients for: % gravel	bottom vegetation	Mean discharge (cfsm)	7-day Q2 (cfsm)	Ratio 10/90% duration discharge	Velocity index	Width-depth ratio	Annual maximum temperature (°F)	Hardness (mg/l)	T divided by 55°F	Standard error (percent)	Multiple regression coefficient	Number of stream segments evalutated
Y	a	G	BV	$\overline{Q}$	Q2	DR	V	WD	T	H	T_2			
Pounds per acre	85.7	0.14	0.18	2.14	-2.13	-1.91					-4.56	89	0.536	88
Pounds per mile	.60	.12	.13					0.64		0.84	-5.08	84	.615	88
Pounds per ac-ft	16.9			3.23	-3.54	-2.98		.59			-3.02	154	.359	88
Number per acre	923	.19									-6.20	135	.398	88
Number per mile	673	.20						.65			-7.47	113	.502	88
Pounds per acre (hardness 0-120)	$1.7x10^{10}$		.34	.98			-.53		-5.14			79	.683	27
Pounds per acre (hardness 120-160)	7.41	.63				-.68						51	.844	21
Pounds per acre (hardness 160)	$1.3x10^{11}$								-5.12			81	.462	44
Pounds per acre (hardness 120)	$3.2x10^{9}$	.31				-.88	-.38		-4.42			77	.559	62
Pounds per acre (temperature 68 F)	.37	.17			.67	.61		-.74		1.29		48	.812	26
Pounds per acre (temperature 72 F)	$2.1x10^{9}$							-.57	-4.96	.95		77	.604	47
Pounds per acre (temperature 75 F)	$1.9x10^{9}$		.16						-5.06	.69		83	.524	64
Pounds per acre (gravel 10%)	$3.7x10^{6}$	.48	.20			-.52	-.38		-3.83	.56		82	.624	72
Pounds per acre (gravel 10%)	87.9		.39	.18				-.79				57	.859	17
Pounds per acre (gravel 20%)	$1.5x10^{6}$	.74	.17			-.57	-.43		-3.90	.59		83	.626	62
Pounds per acre (gravel 20%)	$1.5x10^{7}$		.32	1.25				-.66	-2.87			60	.816	27
Pounds per acre (mark and recapture)	$1.3x10^{12}$	.44	.25	-.88	1.06				-6.01			65	.749	39
Pounds per acre (single survey)	$1.3x10^{6}$								-3.28	.68		95	.437	50

Example.-Trout populations in pounds per acre = 85.7 $(G^{0.14})(BV^{0.18})(\overline{Q}^{2.14})(Q_2^{-2.13})(DR^{-1.91})(T_2^{-4.56})$

DISCUSSION

Trout populations appear to be limited chiefly by stream temperature, hardness of water, bottom materials, bottom vegetation, variability of streamflow, and discharge per unit drainage area. The relatively small correlation coefficients (less than 0.5) of single hydrologic parameters with trout populations in all regressions, using the total sample of 88 stream segments, suggest that populations in a heterogeneous sampling of streams are not dominated by a single hydrologic characteristic. In general, where sample size was restricted to stream segments within certain limits of hardness, temperature, or percentage of gravel bottoms, improvement in the standard error and multiple-correlation coefficients were obtained over that where the total sample was used (Table 2). This improvement reflects a greater homogeneity of the restricted samples.

Temperature of water was one of the most significant hydrologic parameters in almost all regression analyses in which it was included. The mean annual maximum temperature proved to be slightly more significant than the average July temperature. Final regression analyses were run using annual maximum temperatures and annual maximums divided by 55 F. Using temperatures as a ratio to the selected lower limit for trout (55 F) does not change the accuracy in making population estimates from the regression equations but puts the equations into a more usable form. Earlier studies (Benson, 1953) have indicated that temperatures greater than 68 F are above the optimum for brook trout. When the regression analyses were restricted to the 26 stream segments having maximum temperatures of less than 68 F, temperature did not significantly affect trout populations. However, when the regression analyses were restricted to the 47 stream segments having maximum temperatures of less than 72 F, temperature remained the second most important parameter (after hardness).

Hardness was a significant hydrologic parameter in most of the regression analyses except for those restricted to streams having specified ranges of hardness. When the regression was restricted to the 62 stream segments having hardness greater than 120 mg/l the parameter of hardness dropped out early in the regression. This suggests that for hardness values greater than about 120 mg/l trout populations may not improve as hardness increases. All of the soft-water streams (streams having hardness of less than 120 mg/l) are in Michigan's Upper Peninsula and adjacent areas of northern Wisconsin. Most of the hard-water streams are in Michigan's Lower Peninsula and in central and southern Wisconsin. The generally smaller trout populations in the Upper Peninsula, in comparison to those in the Lower Peninsula, reflect, in part, this difference in hardness of the water.

The positive relationship of trout populations to specific conductance of water in five Pennsylvania streams was pointed out by McFadden and Cooper (1964). Specific conductance is highly related to hardness in most fresh-water streams.

Channel characteristics that appear to significantly affect trout populations are bottom materials, bottom vegetation, and width-to-depth ratio. Populations generally are greater in streams having higher percentages of gravel bottom and bottom vegetation. The relationship of width-to-depth ratios and trout populations generally is positive where populations are expressed in pounds per mile and negative where populations are expressed in pounds per acre.

In almost all analyses percentage of fish cover showed a surprisingly poor correlation with trout populations. This may be due in part to the subjectivity of estimates of fish cover. Also, it is possible that fish cover generally is adequate on almost all streams considered, and that cover significantly influenced populations only in those short segments where great differences in cover and in populations may be typical of the stream in general.

The differences in multiple correlation coefficients with different parameters of trout populations suggest that units of measurement of population in either pounds per acre or pounds per mile are preferred to pounds per acre foot or to number per acre or per mile. (The unit of pounds per acre foot is the unit of pounds per acre multiplied by depth of channel). Multiple-correlation coefficients for pounds per mile are slightly higher than those for pounds per acre, and the standard errors are slightly lower. Most individual hydrologic parameters were also found to be more highly correlated with pounds per mile than with pounds per acre. Possibly a parameter of trout populations combining both area and length might show a higher correlation with hydrologic parameters than the units of trout populations used in these analyses.

Variability of streamflow (expressed as the ratio of the 10 and 90 per cent duration discharges, or as the ratio of the mean discharge and median minimum 7-day low flow) was also a significant factor in several of the regression analyses. The negative relationship of variability of streamflow to trout populations was expected, because it is generally recognized that "flashy" streams do not support large populations of trout. For these streams, available cover is greatly reduced at low stages, and shallow depths contribute to warming of the water. At high stages, erosion of banks is likely to occur and sediment deposition may become a problem.

A negative relationship between the ratio of the 10 and 90 per cent duration discharges and specific conductance and hardness is indicated by their relatively high correlation coefficients (—0.65 and —0.70, respectively). This relationship may be explained in part by the fact that the more uniformly-flowing streams discharge relatively large amounts of ground water whereas the more flashy streams discharge relatively large amounts of surface runoff. Ground water in the study area usually is harder and higher in specific conductance than surface runoff.

Stream discharge per unit drainage area significantly affected trout populations in several of the regression analyses. Populations generally were greater where 90 per cent duration discharge or 7-day low flow were large. Streams having high discharge per unit drainage area during periods of base flow generally are those that discharge relatively large amounts of ground water. These streams also generally have a more stable flow than those with a smaller discharge per unit drainage area. A negative relationship between the ratio of the 10 and 90 per cent discharge and the 7-day low flow, in cubic feet per second per square mile (—0.67) is shown in Table 1.

SUGGESTIONS FOR FURTHER STUDY

This is the first study known to the authors that attempts to correlate a wide range of hydrologic parameters with trout populations for a large number of stream segments. Although significant correlations were obtained, improvement in the accuracy of hydrologic and population data would probably improve the results. It is shown, for example, that when the regression analysis was run using only streams for which trout population data were based on the "mark and recapture" method a significant improvement in the results was attained. With this limitation the standard error is 65% whereas analyses for streams having only single survey population counts had a standard error of 95% (Table 2). If more precise data were to be obtained, it may be desirable to test the data for curvilinear relationships as well as straight-line statistical analyses to see whether the correlations might be improved. It is also possible that more accurate data would show relationships not demonstrated in the present study. For example, significant relationships between trout cover and trout populations may be found.

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TEMPERATURE OPTIMUM OF ALGAE LIVING IN THE OUTFALL OF A POWER PLANT ON LAKE MONONA

Thomas D. Brock and James Hoffmann
University Wisconsin—Madison

ABSTRACT

Temperature optima for photosynthesis were measured for algal populations living in the outfall of an electric power plant on Lake Monona and were compared with the temperature optima of algae living in a control area in the nearby Yahara River. The temperature of the power plant outfall averaged about 8°C higher than that of the Yahara River. Studies were carried out in both summer and winter. In the winter, no differences in species composition between the two study areas could be detected, *Cladophora* and *Ulothrix* being the dominant algae. The temperature optima of the populations from the two locations were the same, around 27°C, although the habitat temperatures at both locations were considerably lower. The only difference in response to temperature seen between the two populations was that the population at the outfall was able to photosynthesize at higher temperature, still showing high photosynthesis at 35°C and detectable photosynthesis at 46°C, a temperature at which the population from the Yahara River showed no detectable photosynthesis. In the summer, the dominant algae at the power plant outfall were *Stigeoclonium* and filamentous blue-green algae (family Oscillatoriaceae), whereas at the Yahara River the algal population was almost exclusively *Cladophora*. The temperature optima of both summer populations were the same, 31.5°C, only slightly higher than the mid-winter optima. Again, the population from the power plant was able to photosynthesize at higher temperature than the control population, showing quite active photosynthesis at 42.5°C, a temperature at which the population from the Yahara River was completely inactive. These results are discussed in relation to the possible environmental impact of power plants on Wisconsin lakes and rivers.

Electric power plants in many parts of the world use convenient natural waters for cooling, returning the water to the environment at temperatures higher than ambient. In the mixing zone of heated water discharge, impact on aquatic organisms and ecosystems may occur. One of the presumed consequences of man-made heating is an increase in algal growth and a change in the algal species present (Patrick, 1969). However, few studies have been carried out to verify this assumption. Additionally, there have been no studies to see if the algae developing in such warm water outfalls have become adapted to the temperatures they are experiencing. The availability of a convenient power plant outfall of the Madison Gas and Electric Company on Lake Monona prompted the present study. In a sense, this study supplements and extends a more detailed study which was done by Boylen and Brock (1973) in Yellowstone National Park, measuring the effect of thermal additions from the Yellowstone geyser basins on the benthic algae of the Firehole River. In that study, it was shown that heating of the river resulted in marked increases in algal growth rate and standing crop, but that the algae were optimally adapted to the temperatures that they experienced. Further, the algae retained their mid-summer temperature optima even during the time of the year when the water temperatures were considerably lower due to runoff of melting snow.

It was of interest to see whether algae living in a power plant outfall would retain their mid-summer temperature optima throughout the year. Consequently, the temperature optima of the algae in the Lake Monona outfall were measured both in winter and mid-summer, and were compared to the temperature optima of algae from a control area, the Yahara River, which carries Lake Mendota water into Lake Monona, but whose temperature is not modified by power plant effluents. The results show that the algae in both the power plant outfall and the Yahara River have temperature optima are no higher. The only clear distinction between as with the Yellowstone algae, they retain their mid-summer optima even during cold portions of the season. Despite the fact that the algae in the power plant outfall experience throughout the year temperatures higher than the algae in the control area, their temperature optima is no higher. The only clear distinction between the two algal populations with respect to temperature is that the algae in the power plant effluent are able to photosynthesize at temperatures somewhat higher than the control algae. Additionally, the species composition of the algae in the power plant effluent shows minor differences from that in the Yahara River, although it has not been shown that this is a direct effect of the heating brought about by the power plant, since the two habitats may differ in other, unmeasured ways.

MATERIALS AND METHODS

The outfall from the Madison Gas and Electric Company plant is at the foot of Blount Street, Madison, Wisconsin, immediately adjacent to the Elks Club. The current created by the effluent is very strong immediately adjacent to the outfall, but decreases considerably with distance. The actual flow pattern of the outfall is influenced by wind and current, but there is an area immediately north of the outfall where relatively constant current exists, and samples were taken from this area. It was important to avoid areas of extremely rapid flow because the scouring action of the water prevented significant algal development. The control area on the Yahara River was chosen so that the flow rate was similar to that of the outfall area. In the winter, ice rarely forms in the Yahara River and algal populations were always present. Temperature was measured with a thermistor probe at the site of collection.

Algae were collected by removing rocks containing visibly green material, placing these in plastic bags containing water from the habitat, and returning these to the laboratory. The algae were removed from the rocks by scraping gently with a brush, or by picking algal filaments with forceps. Care was taken to maintain the temperature of the algae at that of the habitat until the experiments were initiated. To avoid any changes after collection, experiments to measure the temperature optima of the algae were done the same day the samples were collected.

The optimum temperature for photosynthesis was measured using a radioisotope method, details of which are described by Boylen and Brock (1973). The filamentous algae were cut into small pieces with scissors and distributed in approximately equal amounts in 5 ml glass vials containing 4 ml water from the habitat. The vials were immersed in water baths at the desired temperatures, allowed to equilibrate for 10 minutes, and 0.1 ml of $NaH^{14}CO_3$ (10 μCi/ml) injected into each vial. Light intensity was held constant at each temperature at about 250 foot-candles using fluorescent lights. In addition to the experimental vials, vials incubated in the dark were used. Uptake of radioactivity in the dark was much lower than in the light, and the dark uptake values were subsequently deducted from the experimental values.

The experiments were terminated by adding 0.5 ml of 40% formaldehyde to each vial. An additional control in each experiment was a vial to which formaldehyde was added at zero time, before the isotope. Formaldehyde controls always showed low uptake of radioactivity. Uptake of radioactivity was linear with time over several hours; in most experiments incubation times of three hours were used. Such incubation times were sufficiently long so that significant incorporation of radioactivity occurred, yet short enough so that secondary effects of incubation were avoided.

For processing, the contents of each vial were transferred to a plastic centrifuge tube, homogenized with a Teflon homogenizer, and 0.5 ml filtered through a membrane filter. The radioactivity of the dried filter was then measured by liquid scintillation counting. The remaining material in each tube was centrifuged, the pellet suspended in acetone, and homogenized again. The tubes were allowed to stand overnight in the refrigerator, centrifuged, and the chlorophyll content of the extracts measured in a Bausch and Lomb Spectronic 20 colorimeter at a wavelength of 665 nm. The radioactivity per vial was then divided by the chlorophyll per vial, so that each sample was normalized to the same amount of chlorophyll. In this way, variations in sample size in the original incubation vials could be obviated. The details of these procedures are described by Brock and Brock (1967).

RESULTS

The measured temperatures of the power plant outfall and the control station on the Yahara River over a one year period are shown in Table 1. As seen, the power plant effluent was always

TABLE 1. WATER TEMPERATURE OF THE LAKE MONONA POWER PLANT OUTFALL AND OF THE YAHARA RIVER NEAR ITS ENTRANCE INTO LAKE MONONA

DATE	OUTFALL TEMPERATURE °C	YAHARA RIVER TEMPERATURE	TEMPERATURE DIFFERENCE
12/8/72	14.9	0.9	14
1/10/73	10.2	1.5	8.7
1/15/73	12.2	2.5	9.7
1/24/73	11.4	3.5	7.9
2/1/73	11.2	3.2	8.0
2/13/73	10.8	3.0	7.8
4/2/73	17.5	6.6	10.9
5/24/73	23.0	15.0	8.0
6/29/73	29.0	21.0	8.0
7/9/73	31.5	25.5	6.0
7/13/73	35.0	27.0	8.0
7/17/73	29.0	26.0	3.0
8/14/73	30.0	24.0	6.0
10/8/73	28.0	17.0	11.0
11/21/73	12.0	8.5	3.5

Average temperature difference between the outfall and the river over the period of study, 8°C.

warmer, and the average temperature differential was 8.0°C. The warmest temperature measured at the outfall, in mid-July, was 35.0°C, and the coldest, in mid-January, was 10.2°C. The winter of 1973 was unusually mild, and ice left Lake Mendota in early March, so that the temperatures of the Yahara River in winter were warmer than normal. In a normal winter when ice does not leave Lake Mendota until April, the temperature of the Yahara River would remain close to 0°C for three or four months.

Winter studies. No obvious differences in species composition between the two study areas could be determined which could be related to temperature differences. At both stations, *Cladophora* and *Ulothrix* were dominant algae, associated with small numbers of pennate diatoms. At the outfall, *Stigeoclonium* was found in small numbers, and in the Yahara River *Rhizoclonium* was seen. The temperature optima of algal samples collected on 1 February 1973 are shown in Fig. 1. As seen, the optimum for both algae was about the same, around 27°C, despite the fact that the habitats of both populations must have been considerably cooler for at least two or three months. The only difference in response to temperature

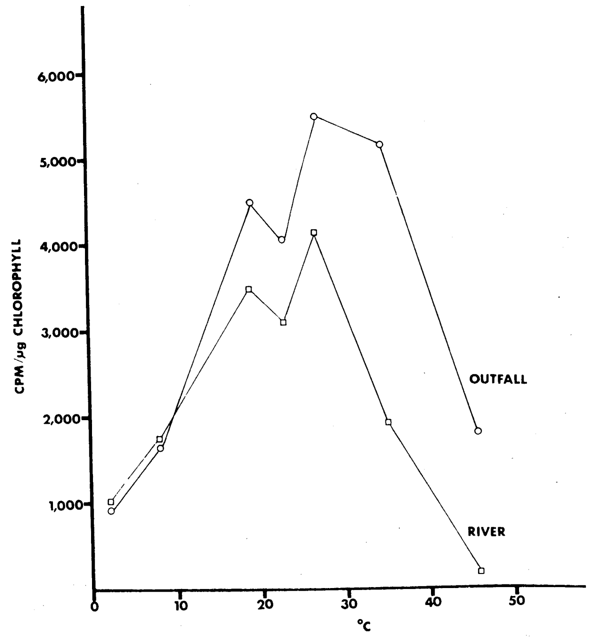

FIGURE 1. Effect of temperature on photosynthesis of algal populations collected at the power plant outfall (temperature 11.2°C) and the Yahara River (temperature 3.5°C) on 1 February 1973.

between the two populations was that the population at the outfall was able to photosynthesize at higher temperature, still showing high photosynthesis at 35°C and detectable photosynthesis at 46°C, a temperature at which the population from the Yahara River showed no detectable photosynthesis. Another experiment was done with material collected on 13 February 1973. Again, both algal populations had the same temperature optimum, but the optimum was now a little lower, a broad peak being seen from 20–27°C. As before, the algal population from the outfall was able to photosynthesize at a higher temperature than the population from the Yahara River. The species composition on 13 February was similar to that on 1 February.

Summer studies. Samples were collected on 14 August 1973, at which time both habitats had been warm for at least 1.5 months. At the power plant outfall, the dominant algae were *Stigeoclonium* and filamentous blue-green algae of the family Oscillatoriaceae. At the Yahara River, the population was almost exclusively *Cladophora*. It is of interest that blue-green algae were never seen in the winter, or at the Yahara River even in summer, and at no time could blue-green algae have been considered dominant.

The temperature optima of the algal populations collected in mid-summer are given in Fig. 2. As seen, the optima of both populations are the same, 31.5°C, only slightly higher than the mid-winter optima illustrated in Fig. 1. Again, the population from the power plant is able to photosynthesize at higher temperature than the control population, and shows quite active photosynthesis at 42.5°C, a temperature at which the population from the Yahara River is completely inactive. Another interesting comparison between Fig. 1 and Fig. 2 is that the actual photosynthetic uptake of CO_2 per unit chlorophyll is much higher in the summer than in the winter algal populations. This presumably reflects the fact that the winter populations are in a physiologically inactive state, either because of the low light intensity or the low temperature at which they are growing. Despite these marked quantitative differences between the populations from the two seasons, the temperature optima are virtually identical.

DISCUSSION

The results of the present studies agree closely with the work of Boylen and Brock (1973) in the Firehole River, Yellowstone National Park, in showing that the temperature optima of algae do not vary throughout the year even though the habitat temperatures do vary widely. The algae in the present study showed virtually the same temperature optimum in mid-winter as in mid-

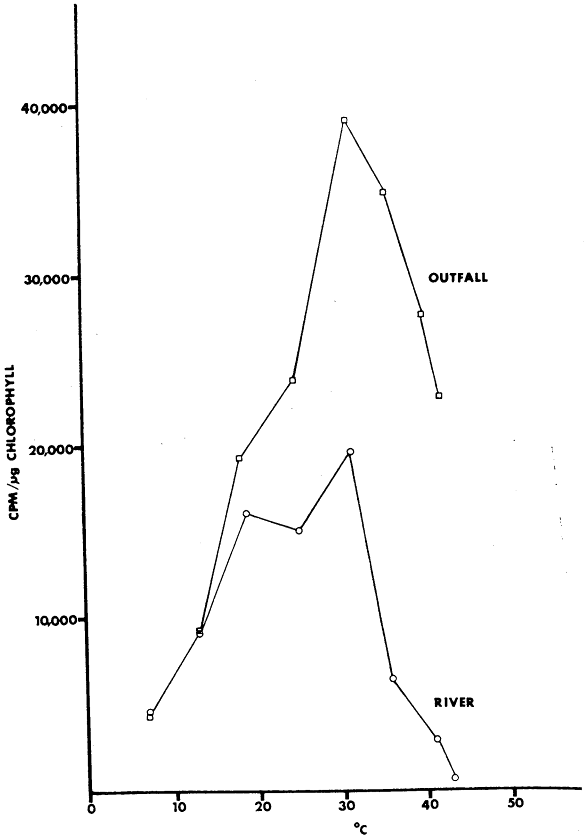

FIGURE 2. Effect of temperature on photosynthesis of algal populations collected at the power plant outfall (temperature 30.0°C) and the Yahara River (temperature 24.0°C) on 14 August 1973.

summer, despite the fact that the habitat temperature was 15–25°C higher in summer than in winter. This suggests that, at least in freshwater environments, algae adapted optimally to low temperatures do not occur. There is evidence in some marine environments of winter algal populations adapted to low temperatures, being replaced in summer by different algae adapted to higher temperatures (Feldmann, 1951). Conceivably, in freshwaters, algae optimally adapted to low temperatures would have no low temperature refuge during the warm summer months, would be killed off, and hence would not be available to colonize during the subsequent cold period. In marine environments, deeper cold habitats may be available as low-temperature summer refuges.

A second conclusion from this study is that a population specifically adapted to the warmer waters of the power plant effluent has not developed. Although it is true that the temperature differential between the two habitats averaged only about 8.0°C, Boylen and Brock (1973) were able to observe adaptation of algal populations to temperature differences even less than these. However, even though the algae at the outfall did not have a temperature optimum which was higher than the control, they did show some ability to adapt to the warmer waters, since it was always observed that the algae at the power plant outfall were able to photosynthesize at higher temperatures than the algae at the control location. It was also noted in every case that photosynthesis per unit chlorophyll was higher in the algae from the power plant outfall than in the control algae, presumably because the former were able to photosynthesize more efficiently. Conceivably, this more efficient photosynthesis reflects an algal population which is growing under more favorable conditions. This may be a temperature effect, but it could also be a current effect, even though some care was taken to select two habitats which had similar current patterns. Some of the difference in the temperature responses of the two algal populations could be due to differences in species composition, and thus only indirectly be due to differences in temperature.

These results, together with those of Boylen and Brock (1973), permit some prediction of the effect of thermal pollution on the development of algal populations in freshwaters. First, since the algae seem to be preadapted to warm temperatures even in the winter, if a freshwater habitat is heated as a result of a new power plant effluent, algal growth should increase in rate, probably resulting in increase in standing crop. Although the present study did not concern algal growth rates, the previous study (Boylen and Brock, 1973) showed clearly that algal growth rate and standing crop were higher in the heated than in the unheated water. Since in both habitats, the algae are preadapted to the warmest temperatures found in the summer, it seems reasonable to predict that increasing the temperature of the habitat artificially should result in increased algal growth.

Second, at the temperatures observed in the present study, blue-green algae never became dominant. This was true even though temperatures at the power plant outfall reached 35.0°C in midsummer. As has been shown in previous work (Brock, 1967, Tansey and Brock, 1972), eucaryotic algae are able to grow at temperatures up to 55–60°C, and only at temperatures above this would exclusively blue-green algal populations necessarily develop. However, in most hot spring thermal gradients blue-green algae are the dominant or sole algal components at temperatures as low as 40°C. Only when temperatures have dropped below 40°C are eucaryotic algae seen to form extensive or dominant populations. Since in the habitats under study in the present paper, the highest temperature seen was 35°C, it is not surprising that eucaryotic algae dominated the populations throughout. Interestingly, some blue-green algae were seen in the power plant effluent in mid-summer, at which time the temperature was the highest, suggesting that the habitat temperature may have been becoming more favorable for the blue-green algae. A reasonable prediction is that if the power plant effluent should increase in temperature above 40°C, the scale may be further tipped in the direction of the blue-green algae and these organisms may become dominant. Such increases in temperature could conceivably occur as a result of increased power plant loading.

From the point of view of thermal pollution, the state of Wisconsin is fortunate in that its natural waters are generally low in temperature, so that increased temperature due to power plant activity does not push the water temperature above the critical 40°C point. In other parts of the country, where natural water temperatures are higher in the summer, an increase of 8–10°C due to power plant activity might have considerably greater effect in promoting blue-green algal development. At least at the moment, there is no reason to believe that the power plant on Lake Monona is having any troublesome effect on algal populations which develop in its outfall.

ACKNOWLEDGEMENT

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A CORRECTION IN SET THEORY

William Dilworth
Beloit, Wisconsin

PREFACE

The logic and assumptions which today comprise the 'foundations of mathematics' often lead to paradox—the name given to a logical but patently absurd conclusion. One may regard paradox with awe, or one may look for underlying errors.

Orthodox mathematical belief today holds that we may take a solid sphere of any fixed size, divide it into a few pieces, and then reassamble those pieces into two solid spheres, *each* of the same fixed size as the first. This theorem, due to S. Banach and A. Tarski in 1924, has been acclaimed as a triumph of modern methods. Logically similar notions weave through the "new mathematics" taught everywhere today.

In the 1924 paper the authors depend explicitly on the work of F. Hausdorff, who was in turn building on Georg Cantor's theory of sets. So either the sphere surgery can be done, and one equals two, or we had better have another look at Cantor's sets. Here I present an analysis, made possible by modern semantics, of a central fallacy in Cantor's theory. The reader will follow my argument without difficulty if he understands that certain endless sequences of fractions have finite limits; e.g., one-half plus one-quarter plus one-eighth, and so on, never totals more than one, no matter how far extended.

This paper expands on the following topics:

Numbers Generally. The Archimedean test for equality or inequality of two quantities enables us to determine, no matter what anyone may claim, whether some given form actually defines a numerical value, or not.

Scalars. The adjective "real" has traditionally been applied to an important technical class of numbers, confusing students and promulgating philosophical haggles. The exact synonym "scalar" number is adopted for its structural implications.

Endless Convergent Summations. General examples of the "one-half plus one-quarter" type of sequence are introduced, along with the compact modern notation in which we can exactly express them. We find that all of the scalar numbers can be so expressed, under the summation symbol. On the other hand, decimals, while practical and convenient, happen to be inadequate to this task.

Given Numbers. To have a "given number", as it is casually put in the literature, some Jones must give it to some Smith. This human condition limits the possibilities in interesting ways.

Permutations. This is the technical word for what we commonly call arrangements, such as the way in which a set of books might be arrayed along a short shelf, ordered say by authors, or by titles, etc. Simple laws define how much total variety of arrangement is possible given, say, twenty books and a shelf which will hold five.

"New Permutations". With the laws just mentioned, we are in a position to refute immediately any claim that someone could produce a new, unexpected, and unpredictable permutation within an already defined system. From this framework of secure knowledge, we are prepared to examine critically Georg Cantor's famous "proof" that the scalar number system is irreparably disordered and disarrayed.

Cantor's Diagonal Argument. This is the cornerstone of Cantor' century of influence on mathematics. He claims always to generate "new numbers", not already in any conceivable list. From our permutational point of view, his manipulations are not impenetrable. We and Cantor agree on the elements (books and shelf) of a system. We then display to Cantor all permutations of the books taken, say, three at a time (a permutation of length 3). In order to find a "new" permutation, Cantor insists on using a greater length—namely, four. Thereupon we display to him all permutations of length four; he retreats to the claim that he should be allowed five. Before modern semantic methods made the present analysis possible, Cantor's ability to produce "new" arrangements, while unseen he increased the length of the arrays to which he had access, appeared almost magical. His claims were accepted—never explained.

Decimal Expansions. The illusion that Cantor has each time come up with a "new number" involves a misreading of the decimal expressions he uses. By a straightforward inspection of decimals, as well as by a general professional consensus, many scalar numbers cannot be expressed exactly in decimal form. He who fails, through a lack of rigor, to remember the limitations of the decimal system, may imagine that he sees in Cantor's truncated decimal forms the "objective real numbers"; he slides into Cantor's subtle mistake.

The literature contains many dire predictions that parts of higher mathematics "would collapse" if any defect in Cantor's theory were ever found. My personal communications with professionals show that many of them share this fear. What are the facts? Nothing solid in mathematics is going to collapse. Certain passages in special arguments may have to be modified. New, possibly fruitful, insights may result.

INTRODUCTION

Georg Cantor, a German mathematician of the late 19th century, fathered the 'theory of transfinite sets'. His remarkable ideas were scathingly attacked by his contemporary, the illustrious Kronecker. Poincare, considered the leading mathematician of the time, was at first intrigued but later became bitterly disillusioned and declared the thing to be a mathematical disease. But Cantor finally won authoritative acclaim from Hilbert and Bertrand Russell, and carried the day. With rare exceptions, critics have been silent to this day.

Direct results of Cantor's theory now appear even in elementary textbooks, and a long deductive chain runs from it to the 'Banach–Tarski' spheres. In a roundabout but hopefully heuristic way, we want to have a good look at the cornerstone of Cantor's system. We are concerned here only with the set-theoretic issues; the quality and importance of some other work done by Cantor is, I believe, beyond dispute.

Numbers generally. Archimedes first gave formal expression to our common intuition as to what constitutes a number or, rather, how we can tell in some case whether we have a number or not. It is often called Archimedes' principle; it is in the strictest modern sense an operational test. Briefly, if C and D are numbers, then just one of the following three cases holds:

a) C is greater than D ($C > D$),
or b) C is equal to D ($C = D$),
or c) is less than D ($C < D$).

If, for whatever reason in a given case, we find that we cannot determine which of these three condition holds, then it follows that C, or D, or both, does not define a number.

It frequently happens, both in practice and in theoretical work, that we cannot make the Archimedean test because, while we have some information about a number, we do not have enough to define it exactly. That is, we may know a *range* within which the number lies, but nothing more. If C is "4 and a little more", the test may fail. Likewise if C is "4 + a remainder". And particularly, if C is given in an incomplete form, such as $4.32\cdots$, then it is in fact impossible to determine whether C is greater than, equal to, or less than 173/40, for example. The meaning of the familiar " $\cdots$ " can become rather subtle, when we get into endless (infinite) series. A small difference between C and D can make a lot of difference in results. If the expression "C — D" appears in a denominator, then our answer may be negative, or positive, or meaningless, depending upon that "little difference".

The exact definition of a number need not be simply in digits. Not only are operator symbols such as + and / regularly used in defining numbers but purely verbal sentences or longer contexts may be used. Anything we can put in mathematical symbols we can also eventually manage to *say*. "A circle's radius over its circumference" defines in simple English exactly one number; by routine operations we can actually compare "half the reciprocal of pi" with any other given value, for equality or specific inequality, as required.

The full scalar number system. All the numbers referred to hereunder will be *scalar numbers*. One scalar number, or *scalar,* defines exactly one point on a lineal scale which is endless both left and right of a zero point and on which a unit length is assigned. A scalar defines one point. Conversely, any fixed point on the line, even if it has been defined only by geometric operations or otherwise, is associated with one unique scalar. Historically, in cases where a geometric or algebraic definition came first, the development of the required numerical scalar became an urgent need. Such needs have always been met and today the scalar number system is considered complete. All modern theories in calculus and analysis assume and depend upon this fact.

The foregoing statements imply that every scalar number is fully defined, single-valued, fixed and constant. I will rigorously adhere to that connotation. When a domain of definitions, or a range of values, is meant, those terms, along with 'function' and 'variable' will be used. One may argue with considerable justification that the multi-level structure of both mathematical and nonmathematical language make some ambiguity inevitable. I will say that it is difficult to be consistently clear but I will try anyhow.

A scalar number is additive in structure. Any two scalars add to form a single scalar. From the theory of algebraic fields: Addition is postulated, multiplication is repeated addition, subtraction is inverse addition and division is inverse multiplication. As would be expected, the latest forms of scalars to evolve are the most general and have an elaborate composition. However, an organized hierarchy of transformations permits us to express even the earliest and simplest scalars precisely in the latest general forms. For the exact representation of scalars generally, two specific numerical frames are available: Continued fractions, and endless series. It is of interest that we can without loss of meaning interchange the adjectives, to say endless fractions and continued series. Also, many people would prefer "infinite" to "endless"—one may consult the dictionary and his own taste.

Endless convergent summations. Although the continued fractions are of profound number-theory interest, bounded summations of endless series of diminishing fractional terms are more familiar and fully adequate for our purpose. In the powerful notation of modern mathematics, the notion of an endless convergent summation condenses to:

$$\text{(1)}\quad \text{S, a scalar,} = \lim \sum_{i}^{n} \frac{a_i}{b_i}.$$

The index i ranges over i = 1, 2, 3, · · ·, to and including n. And n has no upper bound. This is important. The symbol n and the complex symbol $n \longrightarrow \infty$ are used interchangeably in the literature, which interchangeability I fully accept, in the above context. There is a context which does not permit n and $n \longrightarrow \infty$ to mean the same thing, and that is when the series a_i/b_i is such that the partial sums do *not* converge. In that case the "limit of the summation" has no meaning, and the summation itself has a numerical value only when n is *fixed*. In the case we are discussing, (1), the series is defined as convergent and the summation has an upper bound and a limit even when n exceeds any bound, and n then exceeds a still higher bound, endlessly.

After such a paragraph, we need examples. Every so-called 'transcendental' scalar can be genetically expressed in the form shown in (1), although the detailed structure of the fraction a_i/b_i may be quite complicated. For a relatively uncomplicated example, we have

$$\text{(2)}\quad \text{e (epsilon, base of nat. logarithms)} = \lim \sum_{i}^{n} \frac{1}{(i-1)!}.$$

The summation in (2) can be proven never to exceed 14/5, when n increases without limit.

On the other hand, the innocent-looking fraction 1/i, when part of the summation expression

$$\text{(3)}\quad \sum_{i}^{n \longrightarrow \infty} \frac{1}{i},$$ becomes part of a summation that never stops

growing; it exceeds every bound; hence it would be incorrect to precede it with the term "lim" (limit), or to equate it with any numerical or algebraical symbol whatsoever.

When it is understood that the series converges, we can call $\sum_{i}^{\infty} t_i$ a *closed* or *bound* form, because when t_i is given we have, in a finite number of symbols, all the information necessary to expand the series endlessly. But, of course, to get the closed form, we had to use the finite abbreviation "i" to represent the basic, perfectly regular, endless system of integers 1, 2, · · ·. If i did *not* represent a perfectly regular, pre-known system, it would then be *impossible* to expand $\sum_{i}^{\infty} t_i$ to produce a single, definite numerical scalar value.

Given Numbers. Mathematics textbooks often use the phrase "given the number x . ." Let us expand a little on this phrase, the meaning of which is usually taken to be self-evident. To say that someone, say Jones, has *given a number* to someone else, say Smith, means first of all that they both understand and accept a language and a symbol system. It also means that Jones knows techniques by which he can expand that number to any required degree of accuracy, say to n places, and that Smith, independently, can also expand that number to as many places, and that the two expansions will be identical, term by term. It may be easier, in this case or that, to make decimal expansions, but it can always be done also in common rational fractions. Note that Jones can never give Smith the endless expansion itself—only some closed form. Jones and Smith are limited by the conditions of human communication.

Surprisingly, many of the professional mathematicians whom I have consulted over the years resist and refuse to acknowledge the foregoing operational facts. I have been accused of "philosophizing" about the matter. They have insisted that the endless expansion itself can somehow be completed, communicated, and that it alone constitutes the scalar number. Moreover, the requirement for regularity of development of the expansion is not generally recognized. A professor of mathematics at Michigan, with whom I had already discussed these points in person and established some rapport, sent me a well-drafted letter declaring that the successive digits of the endless decimal expansion of a number could be decided by a function on repeated throws of a pair of dice. He was at first non-plussed when I pointed out that his procedure would predictably produce *different* sequences each time it was performed and so that it was, if anything mathematical, a variable rather than a single, definite number. Soon, however, that reasonable man conceded, "By golly, you're right!" Had he written a textbook *before* that exchange, however, his "formula for producing a scalar number" might very well have gone on to classes and, perhaps, to posterity.

Permutation systems. A permutation is an arrangement of some or all elements of a prescribed set. Repetitions of the same element may or may not be permitted. The word 'sphere' (s,p,h,e,r,e) is a six-place permutation of letters from the 26 of the alphabet. One character, e, is repeated. The total possible variety of such six-place permutations is just 26^6, or exactly 308,915,776, a large but clearly finite number. Most of the arrangements do not spell words, of course. The alphabet itself has a fixed, rather small number of characters. Even the total variety of characters and signs available for printing is limited. Obviously, an 'infinite alphabet' would before long contain unrecognizable symbols and has in fact no serious meaning.

Every expression defining a scalar number is a permutation selected from a fixed 'font' of symbols, including digits and operators such as 2, 7, +, /, etc. Each character in the set is a single, uncompounded, discrete character. The word 'permutation' implies, of course, that the characters gain added significance from their position within the arrangement.

Consider now the two digits 0 and 1 of the binary system. It is a universally acknowledged fact that these two characters, plus the point ".", can define every numerical value that is possible in the standard decimal system. This similarity extends in particular to the issue of endless expansions.

We regard the characters 0 and 1 from a permutational point of view, neglecting for the moment their standing as scalar numbers and digits. However, for continuity in the later argument, each permutation is preceded by a point, so we write .0 1, .0 1 0, .1 1, etc. Since the point appears in the same position in every case, it has no bearing on the variety of possible permutations. Let us now see what is the mathematical meaning of "all possible permutations of 0 and 1, to n places, when $n = 1, 2, 3, \cdots$, and so on without end." We could start with $n = 15$, say, and then pick up the smaller values of n in another order, but this would make systematic examination of all the possibilities more awkward. So we start more naturally with $n = 1$.

Let "pm." stand for "permutation". Then a little experimentation quickly reveals the following structure:

All one-place pms.	All two-place pms.	All three-place pms.	All four-place pms.
.0	.0 0	.0 0 0	.0 0 0 0
.1	.0 1	.0 0 1	.0 0 0 1
	.1 0	.0 1 0	and on so,
	.1 1	.0 1 1	through
		.1 0 0	
		.1 0 1	.1 1 1 1
		.1 1 0	
		.1 1 1	

There is a simple law describing the quantitative growth of permutational variety in the above system. The number of elemental characters is 2. Taking j as index for the number of places, the number of pms. in each row is exactly 2^j. *It cannot be more.* Moreover, there is a simple law for the total number of pms. in all rows up to and including the j-th, and that is just $2^{j+1} - 1$. This last sum shows that all the pms. in the system are technically *countable,* i.e., the pms. may be paired off with the integers $i = 1, 2, 3, \cdots$. We note here the elementary fact that the integers *cannot be summed.* That is, $\sum_{i}^{\infty} i$ is a divergent series and has no total. Likewise, $\sum_{j}^{\infty} 2^j$ is divergent, and indeed at a faster rate than $\sum_{\infty}^{i} i$. Nevertheless, the technical property of countability is preserved. We have sketched the structure of any two-character permutational system. With suitable substitutions in the algebraic variables, the same statements hold for the base-ten, decimal system.

"New" permutations. It 'happens', i.e., it is a consequence of our standard, highly abbreviated system for writing integers, that *every* permutation of the set of base-ten digits, without a point, defines an integer. Some pms. are redundant, eg., 03 = 3, but otherwise there are no "spelling rules" needed.

Referring again to the base-two system, suppose now someone comes along and claims that he has a way of constructing a *new* pm., one *not* included in the countable system we have developed above. To common sense, this appears to be impossible. If his new entry has one place, how can it be other than 0 or 1? *Obviously, it cannot.* If his new entry has two places, how can it be other than 0 0, 0 1, 1 0, or 1 1? *Obviously, it cannot.* Common sense is right. If his new entry has n places, how can it be other than one of the 2^n pms. which develop in our countable system? *It cannot.* Only one 'possibility' remains. Does this orderly, fully developed permutational system suddenly fail if n has no upper bound? Why should it?

Still, someone has made the claim, not only that he can produce a new pm. not in *any* list we can devise, but that he has also thereby proved that pm. systems in general are unorderable, that their members cannot be counted off one-for-one with the integers, and that he thus demonstrates that he knows of an infinity *beyond* infinity. If we try to count *his* pms., he says, the integers will become exhausted. "Yes sir," the head of the mathematics department of a Univ. of Illinois section said matter-of-factly to my face, "The integers will become exhausted." Believe it or not, Georg Cantor made these remarkable claims stick with the world's mathematicians of his time, and they stick unto this day. The effects of the Cantorian grip on the professional mind have to be experienced to be believed.

Cantor's diagonal argument. Here is how he proceeds. Cantor invites us to make a list of permutations, and we are to take the position that our list is so arranged as to include all possible pms. Suppose we start:

1st pm.	.0 0 0
2nd pm.	.0 1 1
3rd pm.	.0 1 0
. . .	. . .

Now, Cantor reminds us, one pm. is defined as distinct from another if it differs from that other *in any one specified place.* We agree to this. "So," he says, "because the first digit of your first pm. is 0, the first digit of my new pm. (usually called z) will be not 0 but 1. Therefore, z is not the same as your first pm." "Now," says Cantor, "the 2nd digit of your 2nd pm. is 1, so I make the 2nd digit of z to be 0. And so z is not your 2nd pm. Since the 3rd digit of your 3rd pm. is 0, I make the 3rd digit of z as 1. Therefore z is not your 3rd pm. And so on. I win." Historically and up to this date, *he has won.* The horrendous "alephs" of his endless infinities thunder through the evening skies of academe "with hooves of steel", as the songwriter put it.

You will doubt that anyone could be deceived by the foregoing brief and transparent manipulations. Nor were they. Cantor's historic presentation was in subtly different terms. No discussion of permutational structures preceded his demonstration. He insists that he is dealing directly with the objects of the "real" (scalar) number system, and that therefore their putative un-orderability and un-countability are a matter of the gravest concern for all of mathematics. He declared that his conclusions were forced upon him by compelling logic, against his own will. He made it stick and, if one believes him, one will also come to believe in the Banach-Tarski spheres.

Let us go back to where Cantor says, "And so on." Because, contrary to Cantor's colleagues and even his critics, we have taken pains to analyze and understand in advance the orderly and endless structure of our permutational system, and we do not have to confuse it with "real numbers", we are in a position to object to his calm, "And so on." "You, Cantor, have not seen our 4th pm. yet. It has only three digits; there is not a "fourth" one to work on; and your "new" pm. z = .1 0 1 certainly *does* appear in our list."

Cantor wants to wave aside our statements. "You don't understand," he says. "All such arrays of digits are endless. You have only shown me three places. Every one knows that all real numbers lead to endless expansions . . ." We ask, "Can't we just talk about the pms. first? All numbers are permutations of digits and other symbols. Don't these laws apply?" And at about this point your Cantor(ian) will declare, "Right now I don't care anything about permutations. What I want to do is prove to you the correctness of the diagonal argument, and you are supposed to have written the real numbers all down here and only the endless decimal form will do and closed forms and finite rationals and things like that simply do not matter. They do not matter because they will not help my argument which can only proceed, when you have already written down all the endless decimals and so on." I do not exaggerate.

Now the refusal of the Cantorians to allow us to develop an orderly listing of all scalars by taking one-symbol pms. first, then two-symbol pms., etc., using whatever conventional digital and operator characters are required, is truly ironic. That is because Cantor himself had earlier made mathematical history by proving that all of the first three orders of scalars, namely integers, rationals, and radicals, could indeed be ordered, and counted, and all had the same "type of infinity". It is worth noting that expositors today describe this feat of Cantor's without ever mentioning that he did it by systematically putting all of the *shortest* forms first; then the next longer, and so on. There is, as you may well conclude, no other way of ordering an endless system. Whether subconsciously or not, these writers manage to avoid displaying short *vs* long forms, by sticking to extremely simple cases in ten-base numerals, or by resorting to algebraic symbols which effectively conceal the lengths of the corresponding numerals. At least a part of their interest is clear: They have written many books giving many solemn proofs, confirmations and consequences of Cantor's argument that, alone among all the scalars, the general form employing the summation operator Σ cannot be ordered and counted. Their *desire* to believe is strong, if not profound. The shibboleth, "The n-th digit of z is different from the n-th digit of the n-th number in the list" acts to paralyze the higher centers. Since the simple scalar numeral "3" does not have a "n-th" digit the Cantorians "expand" it with an infinity of zeroes after the point, for no other reason or purpose than to sustain the illusions of the diagonal argument.

Decimal expansions. Let us look at the definition of an endless decimal as "a definite scalar number". First of all, the literature is in fact replete with descriptions of the properties and limitations of decimal expansions which state that some scalar numbers *cannot* be exactly defined by decimals. Yet, in other references, the endless decimals are given *genetic* status as scalar numbers. The endless decimals may be regarded as the actual objects of the real number system, one authority puts it. Now these declarations involve flat contradictions, of course. We could say that mathematicians are only human, but that would *explain* nothing. There is a reason, indeed a *doctrinal* reason, for this anomalous situation.

I want to say here that our modern system of decimal notation is a truly marvelous mathematical structure, thousands of years in development and brought to its present state only during the Renaissance. (Shortly it will be refined a little more, when the clumsy redundancy of "x 10^e" in so-called scientific notation will be replaced by a suitably positioned single e for the power of ten.) However, decimal fractions, wherein the issue of "expansions" arises, are only one of several possible forms for fractions, and of course everyone who is taught arithmetic is taught common fractions, as well. Now it is an elementary but noteworthy fact that, if we actually restrict ourselves to the ten digits and the point, many common fractions can *never* be exactly shown or 'given' in decimal form. Consider a/b = .2592···. This cannot be unambiguously solved for two integers a and b. The best we could say is that a/b is equal to or greater than 162/625 and less than 2593/10,000. Of course this might be good enough for many practical purposes but is not significant in a theory of rational numbers. Recall that the Cantorian diagonal argument implies that a difference in the *n-th* digit is meaningful, no matter whether that might be the 10th digit, or the billionth, or when n increases endlessly.

The integers a and b in the above example can be exactly defined by the *addition* to the decimal system of a conventional but little used symbol called the vinculum (or some equivalent). This is a line over a set of decimal digits meaning that the permutation of digits repeats endlessly in the expansion. In other words, the vinculum is a symbol abbreviating the sentence preceding this one. In many cases, writers modify and circumscribe a numerical expression by a couple of paragraphs of special, one-purpose expository text and then appear to believe that all that complex of meaning actually resides in the numerical itself. It reminds one of the comedians' convention where so many jokes were going about that they were referred to as No. 29, No. 172, etc. When one fellow heard "No. 17" he fell into a fit of laughter, since he had never heard that one before! At any rate, the vinculum is an *addition* to the set of ten digits and the point; it permits us to *drop* one digit from our example and show a/b = $.\overline{259}$, wherefrom a/b is exactly 7/27, and nothing else. Without the vinculum, or some symbolic or linguistic substitution for it, the "endless decimal expansion" cannot define 7/27 or others of that type.

When it comes to so-called irrational numbers, like $\sqrt{7}$, the deficiency of the decimal expansion is far more striking. There is no equivalent of the vinculum for irrationals. Nor can any be invented. For rationals, the vinculum delineates a *pattern* which survives the transcription from the common fraction into the decimal fraction form, and from this pattern the closed form a/b can be exactly recovered. When $\sqrt{7}$ is expanded in decimals, no pattern survives, and hence the original expression cannot be unambiguously recovered. This is all perfectly conventional and well-known, you can check it with anyone, and indeed if you were so inclined could prove it to yourself with some effort and practice. The loss of pattern in an irrational is the cost of expanding it *decimally;* in practice of course it is often advantageous because of the ease with which decimal approximations can be compared with one another, combined with each other, etc.

Perhaps it is not obvious what pattern there actually is in an irrational like $\sqrt{7}$. However, there are many ways to *expand* $\sqrt{7}$ in forms in which the pattern becomes clearly visible and is never lost. Continued fractions, mentioned above, are one. Another is by the expansion of $(6 + 1)^{1/2}$ by the binomial theorem. There are indefinitely many different ways of expanding $\sqrt{7}$ by the two systems mentioned, and there are other systems, too.

So the "endless decimal expansions" cannot give us even a simple radical exactly. But the other systems, including the endless convergent summations, *always* provide closed expressions, not only for radicals but for a still higher form of scalar number usually called "transcendental". These include trigonometric functions, for example, so they are eminently 'practical' sorts of things.

I can assure you that every mathematician will concede the technical accuracy of the foregoing. On some points he may have to do some 'figuring', or long-recalling, but he will concede. As I have pointed out, for mathematicians no less than for the rest of us does a contradiction between two propositions preclude their both being carried in the same head.

So why have the "endless decimal expansions" (or binary expansions, for that matter) been raised to such a status as to be equated with scalar numbers themselves? The answer, I believe, is now clear. Because the open admission that closed forms for scalar numbers, which forms can obviously be ordered and counted, are available in other expansion systems but not in the decimal or binary type, would lead rather quickly to the exposure of the number-theory fallacies in the Cantorian diagonal argument and the deductions made from it. Remember the spheres.

THE FISCHER COLLECTION

James La Malfa
University Wisconsin Center—
Marinette County

The delivery, in November 1971, of the last of the Fischer Collection to the Geology department of the Milwaukee Public Museum represents the finale of a most interesting story. The Fischer collection was donated by me and consists of 296 samples of pigment, dye, minerals, oils and binder used in paint from prehistoric time to the 20th century. The collection also includes a complete Ostwald color wheel in pigment, a post card from Wilhelm Ostwald to Dr. Martin Fischer, Fischer's scrapbook and his notes from lectures on paints delivered all over the United States.

The Fischer Collection has been valued at $4000 by Professor Lawrence Rathsack, art instructor at the University of Wisconsin—Milwaukee. Professor Rathsack, himself an expert on the subject of paint technology, Mr. Joseph Emmuletti and Mr. George Gaenslen of the Geology department, Milwaukee Public Museum, have been most helpful in finding the Fischer Collection a permanent home.

The prime motivation for my writing this article and placing the collection where it is now housed, is to make available to scholars and artists a rich source of information on the history of paint. Mr. Emmuletti, who presides over the collection, has assured me that the items collected by Dr. Fischer, will be made available to any interested party for study, examination and photography.

In August 1968, Mr. Louis Voight, Seminary Librarian at Wittenberg University, Springfield, Ohio, called me and asked if I would like some paint. I was an art instructor at the time in Wittenberg's art department and Louis was a friend and neighbor. Although my specialization is drawing and sculpture, I replied in the affirmative, more from curiosity than any other motive. I met Louis in the Thomas Library basement and he showed me some dirty cardboard boxes which, he said, the library was planning to discard because they lacked sufficient storage space.

I opened one of the boxes of "paint" and observed a carefully labelled collection of jars, capped and sealed with sealing wax. This was, I reflected, most unusual paint! Thus my curiosity was aroused by my first glance at the pigment collection of Dr. Martin Fischer. I was determined to uncover the reason for the collection and facts about the man who assembled it. Every box marked "Fischer Collection" was moved to my studio where I proceeded carefully to open and catalog each box and each item. The number of boxes totaled fourteen, most containing notes in pencil by Dr. Fischer, describing the contents of each.

Each group was assigned a letter, A to N, and I carefully copied down the contents of every bottle. Copies of the resulting catalog are in Mr. Emmuletti and Professor Rathsack's files. A perusal of the catalog indicates the order of a careful, scientific mind. Box A, for example, contains all of the whites and blacks ever used as pigment. It is interesting to note that of twenty-two specimens of white pigment, many, listed under proprietary names, are chemically identical to other whites with different proprietary names. For example, Chremmitz, Silver, Flake and Lead white are all lead carbonate.

Of the ten samples of blacks, asphalt and asphaltum are the same. Cork black and lamp black are identical, basically sooty carbon. The two samples of blue-black are graphite. Although not true blacks, Fischer included sepia and mummy as examples of warm blacks which were utilized by 19th century artists. Sepia is squid ink and mummy is literally that; ground up Egyptian mummies! The last worth mentioning is bister (bitumin lake), an analine dye co-precipitated on a clay base. Genuine bister is asphalt.

The fact of the matter is that each sample in this group and every other sample in Dr. Fischer's collection are there for a reason. Either the pigment is historically significant because it was a bad pigment or because it was a good pigment.

Box A also contains samples of mineral pigments used by Medieval and Renaissance artists. Box B contains lakes, madders and various oils and varnishes used as binders. Box C contains stearates and phenols, Box D some reds and browns, Box E a series of ochres and yellows and Box F miscellaneous pigments.

Box G included a note by Dr. Fischer: "Color change from yellow to red due to change in size of particles—9 bottles." These pigments demonstrate the fact that, although chemically identical, the cadmium yellow (light, medium, dark), oranges and reds depend upon the size of the grind to determine their value. The coarser particles appear darker.

Box H contains a mixed group of lake (analine dye) colors and assorted types. Box I, is according to Dr. Fischer's note, "Color types—Earths." Box J is labelled "A series of the natural sources of the dye" and includes samples of madder root from which the Egyptians first extracted a red dye called Alizarin Crimson, and Cochineal, dried bodies of an insect which yields a brilliant red, Carmine, introduced to European artists in the 17th century. There are 16 samples in this group and one of Dr. Fischer's lectures to the Art Student League of New York, on sources of the dye, suggests the reason for the inclusion of these samples. In addition, Box J contains 18 bottles labelled "Color type pigments—blue-green series." Boxes K and L contain a complete Ostwald color wheel, in powdered pigment.

In order to puzzle out the series, I researched Wilhelm Ostwald. Dr. Martin Fischer was a friend of Ostwald and co-authored several books with his son, Wolfgang. I assembled biographical information on Wilhelm Ostwald and obtained the book *Basic Color: an interpretation of the Ostwald color system* by Paul Thebald. A thorough reading of the book gave me the key to Dr. Fischer's series of coded envelopes.

The color sphere is stored, in Box K, a multidrawer wooden box. Each compartment contains 24 envelopes and a letter code. It was now obvious what Fischer had done. Each of the compartments contains all of the 24 colors which Wilhelm Ostwald placed around his color wheel. The letters on each package indicate the black and white content and can be assigned a position thusly on one triangle leaf of a three dimensional Ostwald color sphere. Each group of color packs in Dr. Fischer's series are equal white and black circles or horizontal circles from the Ostwald sphere. The white and black content remains equal all around the 360° of the sphere but the hue changes from #1–24 (yellow to green). If one were to add a binder to these coded pigments, one could produce a complete color sphere.

Box M contains "Gums and oils used for making water and oil color" and 20 samples of "Minerals—Natural—Colored."

Box N contains what Dr. Fischer called his O and S system. This consists of four wooden frames, much like test tube racks. The first is marked S and like the others, contains a series of pigments in glass tubes. In a conversation with Henry Levison, founder of Permanent Pigments, Inc., and himself a color chemist, Fischer's O and S concept was discussed. "It was," said Mr. Levison, "correct in theory, but not necessary. The O colors (oxides) supposedly could not be mixed with vermilion, whereas the S (sulfides) could be." This follows one of Dr. Fischer's conditions for permanency of pigment which states that pigments should not interact chemically with each other within a painting.

Vermilion, discovered by the Egyptians, is a brilliant red called Cinnabar by the Renaissance artists and is sulphide of mercury.

Mr. Levinson continued, "The breakdown of Vermilion was due more to interactions with foreign substances in the earths (ochres), not the earths themselves. Thorough washing of the earths by the

Permanent Pigments, Inc. has eliminated any bad effects of earths on Vermilion."

The other three racks contain the remaining S and two O series of pigment. Box N also contains panels of oil paint which Dr. Fischer tested for fading with exposure to hydrogen sulfide (H_2S). These very same panels are reproduced in Dr. Fischer's book *"The Permanent Palette"* (Plate II p. 12—Effects of air pollutants on some pigments). Incidentally, plate 1, p. 38, "Effects of light exposure on some pigments," which shows the effects of ultraviolet light, was also found in this group of lecture notes. It consists of a series of strokes of water color pigment on paper, some exposed to sunlight, the others not.

With the Fischer collection safely stored in my studio, I spent the remainder of my stay at Wittenberg researching Dr. Fischer. I have included a biographical sketch of Martin Fischer from the Wittenberg University Publication "Alumnus", in the Appendix.

It should be obvious that Martin Fischer was a man of many talents and interests, well traveled and internationally known. He was a prodigious correspondent and the Thomas Library at Wittenberg has, in its archives, virtually every letter Dr. Fischer received and saved during his lifetime. The letters are housed in bound containers by year and contain many insights into Dr. Fischer's personality and interests.

I began sifting through the letters from 1929–1930 because 1930 is the year during which the book *"The Permanent Palette"* was published. The letters from publishers beginning in January 1929 provided a running commentary on Fischer's efforts to get his book published. A letter dated January 3, 1929 from Bridgeman Publishing Company, a firm that specialized in art books, states "We are reviewing your manuscript." A letter from Bridgeman dated March 23, 1929 rejects the manuscript. A letter dated August 10, 1939 from publisher Charles Thomas, provides some interesting comments on art and artists. Thomas rejects the manuscript because he feels it is too well written for an artist!

> Dear Dr. Fischer:
>
> One of my friends has the largest book decorating organization, another is the second largest buyer of colors, in this country. "The Permanent Palette" was read by both with great interest. Both are artists, and employ some of the best artists in the country. Both feel that the manuscript is written with the authority on the chemistry of color, but express the belief that there will be a very limited sale for the book, for the reason that they believe it is too scientific in character to hold painters. They say it is almost impossible to get artists to take time or make the effort to undertake serious study of color. Louis Kreiger, a Baltimore artist, who has worked out with the physics department of the Hopkins, the most superior color Atlas that I have

seen, as well as Priest, of the Bureau of Standards, deplores the lack of attention of artists to scientific fundamentals. They want to be absolute free lances, seek no guidance.

I hate to tackle a crowd that does not desire knowledge as much as I would like to do the MMS for the sake of the subject it represents. So I have taken the liberty of returning the manuscript, not because it is not good, but because of the special difficulties to be encountered.

Faithfully,
Charles C. Thomas

Eventually the book was published by the National Publishing Society (Fischer, 1930), and contributed to a reform of certain questionable practices within the art products industry. From the Thomas Library archives I turned my attention to the Alumni book collection. The library had two copies of *"The Permanent Palette"*, one of which I copied and eventually gave to Professor Lawrence Rathsack.

I read the book and reread it looking for a key to Fischer's pigment collection. The book itself and its basic format are the framework within which the collection made sense. In the *Introduction* Dr. Martin Fischer states his thesis; modern painting as a craft is declining. Many 19th century painters were seduced by the spectral colors of analine dye pigments (lakes) and other non-permanent pigments and their work has dulled in a relatively short period. Fischer attributes this to the artists' ignorance of the chemistry of paint, and his book is an attempt to remedy the situation.

Dr. Fischer's medical interests led him to study the colloidal suspension of water in the cell. Thus when he turned his attention to paint, also a colloidal suspension, he approached his subject in a scientific and analytical manner. According to Dr. Fischer, the following factors affect color permanence: (a) light, (b) air, (c) intermixture with other colors, (d) reaction with the binder (medium), (e) reaction with the ground (primer) on the support (canvas, paper, plaster) and (f) cold or warmth. To Fischer's list I would add the use of non-permanent binders and pigment, exposure to atmospheric pollution and shoddy craftsmanship as the greatest destroyers of paintings in the last one hundred years.

PHENOMENA THAT AFFECT PIGMENT

The ultraviolet portion of sunlight is a strong bleaching agent. It tends to break down all but the simplest pigments such as the ochres or cadmium compounds. Obviously, the informed collector will not hang his paintings in direct sunlight. However, even artificial light will cause non-permanent pigments to fade.

Virtually all manufacturers of paint test their products for light fastness. Permanent Pigments, Inc. tests their paints in the following manner: panels covered with pure paint and tints are mounted at a 45° angle. They are exposed for a six month period to outdoor sunlight. Then they are tested for fading with a colorimeter. These paint tests are run at Cincinnati, where the home plant is located and at Miami, Florida where a branch plant is located. Interestingly, the samples at Cincinnati faded more than those at Miami, although subjected to less intense sunlight and fewer hours exposure. The extreme fading at Cincinnati is said to be caused not by sunlight but by pollution in the air. Samples are also tested indoors, subjected to fluorescent light at a distance of six inches. Both pure and tinted hues are tested because, in use, artists seldom use pure colors. Tints tend to fade more quickly than pure colors.

Why this great concern with fading? Did the artists of past centuries experience this difficulty? No, not at any rate until the 1850's, for up until then all commonly used artists' pigments, even the synthetic ones, were permanent. The first *organic* synthetic pigment was Mauve, created by William Perkins in 1856. This pigment was a dye derived from the destructive distillation of coal tar. The dye is precipitated on a white earth (alumina) also called white clay. The result is the impermanent *analine lake.* All lake colors are dyes characterized by their intense spectral hue, a large and complex molecule, and by their impermanence.

All of these analine lakes with the exception of Alizarin Crimson proved the undoging of the artists who used them, attracted by the brilliance of these *lakes*. Fischer mentions Charles Duveneck and James Abbott McNeil Whistler as two artists whose paintings experienced fading, to which list I might add many lesser known artists, numbering in the hundreds.

Alizarin Crimson, (surrogate) $C_{14}H_8O_4$, resembled and replaced traditional Alizarin, which was first used by the ancient Egyptians. Traditional Alizarin is a dye extracted from the root of the madder plant. Its 19th century substitute proved to be the only early analine dye to be light fast. The other lakes all faded and, even today, many artists consider dye colors suspect.

Dr. Fischer mentions air as potentially destructive to paint. The effect of pollutants in our atmosphere is well known in 1973. The pollutants in question are sulfide, sulphur dioxide, sulfuric acid, carbonic acid, and water. Sulfide will cause lead white to yellow or blacken in the following manner: the hydrogen sulfide produced when coal or gas is burned acts upon lead carbonate and lead hydroxide components of white lead and changes them to lead sulfide which can appear yellow, orange or black.

What then is a safe palette? Dr. Fischer describes the permanent palette on page 33, chapter 7:

Black-Ivory black
Blue-Ultramarine blue
Green-Chromium oxide (Viridian)
White-Zinc white
Yellow-Pale cadmium
Yellow-Middle cadmium
Orange-Cadmium
Red-Cadmium

May also use: Vermilion-Yellowish to orange
Earths
Yellow-ochre-Light
Yellow-ochre-Dark
Gold ochre
Raw and burnt sienna
Raw and burnt umber
Mars yellow (earth)
Mars red
Mars purple

These colors are: light resistant, fairly bright, and incapable of chemical reaction with each other and elements in the air.

If additional colors are needed, these may be added: Blue-Cobalt, Blue-Cerulean, Green-Cobalt, Violet-Cobalt and Green-Terra verde.

Dr. Fischer recommends, as a primer for linen, one part zinc white with one part lead white cut with turpentine. His preferred medium was raw cold pressed linseed oil, bleached by sunlight. He cautions against the use of boiled linseed oil or of driers and siccatives.

The preferred varnish would be pure cold pressed linseed oil or as a second choice, resinous varnishes such as Copal, Damar, Mastic or Amber. The recommended solvent for thinning oil paint is gum spirits of turpentine.

As stated earlier, my purpose in writing this paper is to encourage other scholars and students interested in artists' paints to pursue the subject, using an extremely valuable tool, the Fischer Collection. Those wishing to examine the specimens should contact Mr. Joseph Emmuletti of the Milwaukee Public Museum. I would also be happy to supply additional information such as the catalog of the collection and related data. In addition, researchers should try to locate copies of Fischer's "*The Permanent Palette*" published in 1930; see *References*.

Let me conclude with a brief aside. In January 1973, I received a letter from Miss Ilo Fischer, Thomas Library, Wittenberg University, stating that the last remaining samples of Dr. Fischer's collection had recently been uncovered in the library storeroom. "Would I like them sent to me?" Indeed I would was my reply. This mini-collection was then sent to me by Mr. Louis Voight.

I have merely hinted at many possibilities for further study regarding paint and would like nothing better than to see these areas researched in depth by other scholars.

THROUGH HISTORY WITH THE FISCHER COLLECTION

The following list summarizes some of the more important pigments as they were introduced in various Asian and European epochs. Each italicized pigment is found among the specimens in the Fischer collection.

The first group illustrates some of the pigments used by prehistoric artists. *Yellow-Limonite* or yellow ochre—an iron oxide, *Red Ochre*—red iron oxide

The next sample was used in the ancient Middle East or Mesopotamia and is *Black, Bitumen or asphaltum*

Egyptian artists used the following: *Green, Malachite*—copper carbonate, *Red, Hematite*—red iron ore, *Blue, Azurite*—blue copper carbonate, *Red, Alizarin Crimson*—a dye from the madder root, *Bright red, Vermilion or Cinnabar*—mercury compound, *Yellow, Orpiment*—arsenic compound

During the Middle Ages and up to the Renaissance all of the above were used plus the following: *Black Ivory*—charred ivory, *White Lead*—lead carbonate, *Indigo Purple*—dye from the Indigo plant

The Baroque and Rococo periods saw the introduction of: *Cobalt Blue*—ground smalt (Venetian glass), *Red, Minium*—red lead oxide, *Naples Yellow*—antimoniate of lead, *Orange Realgar*—disulphide of arsenic, *Cambode Yellow*—solid resin from Cambodia, *Carmine Red*—dye from the cochineal insect, *Verdigris Green*—made by mixing fermented grapes and copper (copper acetate).

The first pigment to be synthesized from raw materials was discovered by accident, Diesbach's blue, in 1704. The color is now called Prussian blue or Berlin blue after the nationality of its discoverer: *Prussian Blue*—iron ferrocyanide.

Cobalt Blue followed in 1802 and is cobalt oxide plus aluminum oxide.

Ultramarine Blue was synthesized in 1824 and is thought to be colloidal sulphur in a glassy matrix.

Viridian, a dark green, was synthesized by Guignet, a Frenchman, in 1838. It also goes by the name Verte Emeraude, or chromium green, and is hydrous chromic oxide.

Cerulean Blue was created in the 19th century by mixing Cobalt Blue with tin oxide, a white pigment. It is actually a tint of Cobalt Blue.

Zinc White was also developed in the 19th century and is zinc oxide.

As stated before the first organic synthetic pigment was *Mauve* which is precipitated on alumina, or clay. Mauve and other analine dye colors, as first produced, proved to lack light fastness.

In the early 1900's, two inorganic pigments were introduced which are light fast. They were: *Titanium White*—titanium oxide and the *Cadmium pigments* which are based on chemically pure cadmium sulfo-selenide. They range from Cadmium Yellow to Orange and Red. All are identical except for the particle size of the pigment. The finer sized are lighter.

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RESOURCE PEOPLE

MISS ILO FISCHER, Research Librarian, Thomas Library, Wittenberg University, Springfield, Ohio.

MR. HENRY LEVISON, Permanent Pigments Inc., 2700 Highland Avenue, Cincinnati, Ohio.

PROFESSOR LAWRENCE RATHSACK, University of Wisconsin—Milwaukee, Art Department.
MR. JOSEPH EMMULETTI, Geology Department, Milwaukee Public Museum.

APPENDIX

"Alumnus"
May 1962
Wittenberg University
Springfield, Ohio

MARTIN H. FISCHER

Dr. Martin Fischer, widely-known and versatile man of science, art, and letters who directed the Department of Physiology and taught at the University of Cincinnati College of Medicine for 40 years, died January 19 at his Cincinnati home after a long illness. He was 82.

Dr. Fischer received Wittenberg's honorary Doctor of Science degree in 1932.

Dr. Fischer was one of those rare teachers who sparked interest in medicine and other areas of the mind in generations of students. His wide capacity for friendship made him one of the city's best known and loved persons.

Dr. Stanley E. Dorst, '19, '48H, dean of UC's College of Medicine, called Dr. Fischer "a unique person."

"Not only was Dr. Fischer a physiologist and brilliant lecturer, he was also an artist of considerable ability and a man of literature," Dr. Dorst pointed out.

"His translations of Gracian's 'Truth-telling Manuel' is a classic and his books on the lives of Christian R. Holmes and William B. Wherry are monumental works.

"During Dr. Fischer's term as director of the Department of Physiology, two special units were developed with his aid and encouragement. These are the widely-known Kettering Laboratories in the University of Cincinnati Medical Center and Tanners' Council Research Laboratories on Cincinnati University's main campus. Both were outgrowths of experimental work then going on in the Physiology Department."

In physiology Dr. Fischer was known for his early work in the investigation of the colloidal chemistry of body tissues and for his textbook on physiology of alimentation. Best known of his medical writing was the book *"Edema and Nephritis."*

Dr. Fischer and his wife were major benefactors of Wittenberg. Mrs. Fischer who preceded him in death, bequeathed the University $127,000. Additional bequests from Dr. Fischer will raise the total to approximately $220,000.

Through the years Dr. Fischer made numerous gifts to Wittenberg including rare books, first editions, maps, and works of art.

His total benefactions include about 2,500 volumes, 350 bound periodicals, several hundred monographs on medicine and fine arts, valuable pieces of art and a collection of medals from the Society of Medalists.

He also gave the University a 700 year old Catholic Breviary containing what is believed to be one of the earliest forms of the Rosary. The embossed hand-lettered Breviary, illuminated in color and gold leaf, is the most valuable single item in Wittenberg's rare book collection.

Dr. Fischer's experiments in the pigments of oil paint resulted in the art pigment industry in America. He gave Wittenberg the sequence of pigments that he used for his experiments. His book, "*The Permanent Palette,*" resulted from this research.

Among the paintings given to Wittenberg by Dr. Fischer were some of his own works; paintings representative of the beginnings of Japanese fine art, including prints by the famed Japanese artist Kunisada; oil paintings by Miss Dixie Seldon, landscape and portrait painter of Cincinnati; and John Weis, a portrait painter.

Dr. Fischer had served as director of the Department of Physiology at the University of Cincinnati College of Medicine for 40 years before retiring in 1950. His key contribution in the area of physiology was in the area of colloidal chemistry of body tissue.

A PRELIMINARY SPATIAL ANALYSIS OF QUALITY OF LIFE IN MILWAUKEE COUNTY, WISCONSIN

Richard A. Karsten
University Wisconsin—Milwaukee

Harold McConnell
Florida State University—Tallahassee

Thomas D. Patterson
Northern Illinois University—DeKalb

INTRODUCTION

The United States is a metropolitan nation: two-thirds of its population lives in urban counties comprising Standard Metropolitan Statistical Areas. Moreover, ninety per cent live in or within commuting distance of these urban areas. Despite the fact that urbanization is generally equated with economic growth, metropolitan areas are deteriorating physically, socially, and economically as the urbanization processes continue. In fact, many failures in urban planning can be traced to lack of understanding of relationships between social factors or conditions and economic and physical parameters of urban systems. In short, there must be an optimization of what people deem important within a social context at the same time that economic and physical parameters of urban systems are directed toward meeting a number of explicit goals (Michelson, 1970).

THE STUDY

The social environment of a metropolitan parcel is mirrored by the socioeconomic health or quality of life of that area. This study compares three quality of life attributes elicited from a mix of 42 socioeconomic variables for 43 geographic areas or neighborhoods in a representative urban area, Milwaukee County, Wisconsin, to determine how quality of life varies spatially. Where quality of life differs from place to place, certain urban activities are supported, others are elicited, and still others are depressed as stress develops which may evolve into urban strain (Michelson, 1970). This study will attempt to depict the spatial variation of potential urban strain as it is reflected in quality of life in Milwaukee County.

Quality of Life Factors

Zwerdling (1973) suggests that the basic environmental problems of urban life have, as their origins, blight and poverty which are in turn reflected in the quality of life of city dwellers. Stellman (1973) states that more immediate indicators of blight and poverty, such as state of health, educational level, housing quality, income level, and employment status, are the basic ingredients of the quality of life of an urbanscape. The 42 socioeconomic health indices analyzed here mirror these components in Milwaukee County. With respect to the neighborhood level of aggregation of the study, as Rose (1969; 1971) suggests, the neighborhood may be considered to be a social area consisting primarily of persons of a single race and having similar subcultural characteristics that operate and interact in a complex system of social and economic constraints at various levels. Furthermore, the neighborhood can be considered to be a socioeconomic-spatial institution which is an outgrowth of complex socio-psychological decisions which are influenced by the operation of economic forces (Rose, 1969).

The Immediate Environment and Quality of Life

Much of the ongoing research concerning environmental matters focuses upon man's activities and interactions with the physical environment, e.g., the land, the water, and the ambient air. These may be considered epigene factors as opposed to the hypogene factors that comprise the human or cultural environment. These sets of factors do, indeed, interact with one another in a dynamic system of inter and mutual dependence. However, for convenience they may be treated as separate entities. The epigene factors primarily constrain place utility of the generalized environment (Austin, 1971) and are outside of the scope of this study, while the hypogene factors are composed of "people organized and interacting in a group (society) and a distinctive way of life shared by members of the group (culture)" (Commins and Fagin, 1954). In the microcosm this concept may be scaled to the individual dwelling unit which becomes the immediate society, while the neighborhood becomes the culture.

In order to evaluate the quality of life (mental well-being and social satisfaction) of man, it is implicit that his immediate environment be considered in the context of the home as it is reflected in his neighborhood or culture. Commins and Fagin (1954) consider that the immediate environment is of far greater importance in human development and quality of life than the physical environment (except for its extremes). Although the home and neighborhood are tangible entities, they should be considered the result of societal fabrication (Marcus and Detwyler, 1972). These societal fabrications are mirrored in what Lynch (1960) calls the perception phenomenon of the city.

Michelson (1970) has approached the quality of life in urban areas by reducing social life into five basic components: life style, stage in the life cycle, social status, value orientation, and personality. It is implicit in Michelson's analysis that various measures of socioeconomic health would reflect varying levels of quality of life in urban areas.

Scale of Research and Data Collection

Beverstock and Stuckert (1972) have divided Milwaukee County into community areas, using methodology developed by the Social Science Research Committee of the University of Chicago (1963) (see Figure 1). These community areas are treated as neighborhoods here, since their delineation was based upon criteria which include internal homogeneity of various socioeconomic attributes. Wolpert, *et al.* (1972) points out that although neighborhoods are difficult to delineate, the neighborhood unit and the home or immediate environment are the most incisive units for urban analyses. Although Michelson (1970) considers neighborhood to be a "slippery term," he suggests that cohesive delineation of such units is the most viable approach to urbanscape analysis.

The same authors (Beverstock and Stuckert, 1972) also collected and developed socioeconomic data from 16 U.S. Bureau of the Census sources for the Milwaukee S.M.S.A. and its various components, including the community areas or neighborhoods of Milwaukee County. These data include general characteristics of the population, housing, marital status, age, sex, race, families, households, labor force, occupation, income, nativity, ethnicity, vital statistics, infant mortality, mobility, and educational level. Forty-two variables were selected from the above set which were deemed to be measures of socioeconomic health for the 43 community areas or neighborhoods of Milwaukee County and which possess those attributes which reflect quality of life or the populations' mental well-being and degree of social satisfaction (see Table 1). The County Institutions community area is not included in this study.

The Analysis

As is characteristic with geographic data bases, none of the indices is arrayed in accord with the normal probability law. Each of the variables exhibited positive skewness and was transformed into its common logarithm prior to the analysis of the data.

Principal Component Analysis. There are numerous redundancies among the 42 incides which were deemed to describe the socioeconomic health of Milwaukee County. Principal components analysis was employed to collapse this set of colinear variables into a smaller number of basic dimensions which are the mutually inde-

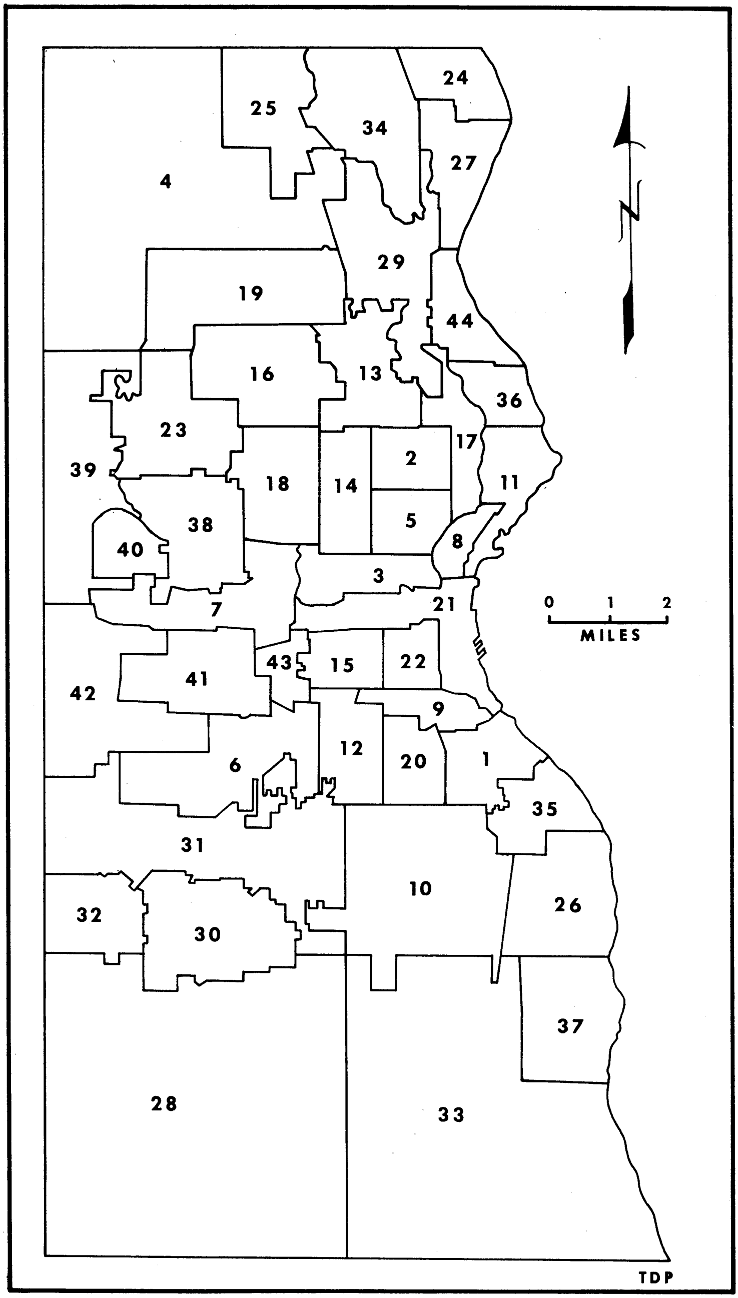

FIGURE 1. Location of Milwaukee County community areas (after Beverstock and Stuckert, 1972)[4]

[4] County Institution community area 40 is not included in this study.

LEGEND FOR FIGURE 1

Identification Number	*Community Area*
	City of Milwaukee
1	Bay View
2	Garfield
3	Grand Avenue
4	Granville
5	Halyard Park
6	Jackson Park
7	Johnson's Woods
8	Juneautown
9	Kosciuszko
10	Lake
11	Lakeside
12	Layton Park
13	Lincoln Creek
14	Midtown
15	Muskego Avenue
16	North Milwaukee
17	Riverside West
18	Sherman Park
19	Silver Spring
20	Tippecanoe
21	The Valley
22	Walker's Point
23	Wauwatosa Avenue
24	Village of Bayside
25	Village of Brown Deer
26	City of Cudahy
27	Village of Fox Point
28	City of Franklin
29	City of Glendale
30	Village of Greendale
31	City of Greenfield
32	Village of Hales Corners
33	City of Oak Creek
34	Village of River Hills
35	City of St. Francis
36	Village of Shorewood
37	City of South Milwaukee
	City of Wauwatosa
38	Wauwatosa East
39	Wauwatosa West
40	County Institutions
	City of West Allis
41	Old West Allis
42	West Allis Addition
43	Village of West Milwaukee
44	Village of Whitefish Bay

pendent (mathematically orthogonal) attributes of the variables. Similar procedures were employed by Thompson, *et al.* (1962) in a study of economic health in New York State and by McConnell (1970) to analyze the socioeconomic health of large Illinois municipalities. The method is described in brief in the following general statement.

Overview of Methods and Procedures. The straight-forward objective of principal components analysis is to transform a set of m standardized variables into a set of m orthogonal variables. However, it is generally used to collapse m standardized variables into a smaller set (p) of orthogonal variables or fundamental attributes of the original variables. Denote the following:

- Z — N $\times$ m matrix of standard scores
- R — m $\times$ m matrix of Pearson product moment correlations between the standard scores
- P — m $\times$ p matrix of correlations between variables and attributes
- P^t — p $\times$ m transpose of P
- P' — m $\times$ p varimax rotation of P
- C — N $\times$ p matrix of standard scores on the attributes

Each variable is standardized about its mean. Correlations between the standardized variables are arrayed in an m × m matrix (R) which is subjected to the principal component analysis to transform the original indices into mutually exclusive attributes or principal components:

$$\left(Z_{X_1}, Z_{X_2}, \ldots, Z_{X_m}\right)$$

TABLE 1. VARIABLES AND PRINCIPAL COMPONENTS ANALYSIS

Component	P_1	P_2	P_3
Eigenvalue	21.22	7.23	3.49
Percentage of total variance in R	50.50	17.20	8.30
$p'_{ij} \geqq .50$	p'_{i1}	p'_{i2}	p'_{i3}
Variables			
Per cent of Black population			—.84
Population density per square mile			
Population change (1970 population as a percent of 1960)	—.75		
Per cent of population of foreign stock		—.55	.71
Median age of males		—.69	.50
Median age of females		—.82	
Median school years completed by persons 25 years and over	—.91		
Median family income	—.86		
Per cent of males 14 years and over in labor force			.61
Per cent of females 14 years and over in labor force			
Per cent of total housing units owner-occupied	—.53		
Per cent of total housing units owned by nonwhites			—.78
Median value of housing units owner-occupied	—.90		
Per cent of total housing units renter occupied	.66		
Per cent of total housing units occupied by nonwhite renter	.51		—.80
Median contract monthly rent	—.84		
Per cent of population under 5 years		.78	
Per cent of population between 5–19 years		.87	
Per cent of population 60 years and over		—.95	
Per cent of persons 14 years and over in civilian labor force employed as professional, technical and kindred workers	—.93		
Per cent of families with annual incomes of less than $6,000	.84		
Per cent of families with annual incomes of more than $15,000	—.93		
Per cent of population of Spanish origin or descent	.87		
Birth rate	.64		
Fertility rate	.74		
Death rate		—.79	
Net migration (1960–69) as a percent of total population	—.58		
Infant mortality rate			—.51
Fetal death rate			
Per cent of persons 5 years and over living in same residence in census year as 5 years earlier			.60
Per cent of persons 25 years and over completing high school			.60
Per cent of persons 25 years and over completing 4 years or more of college	—.94		
Per cent of owner-occupied housing units valued at less than $10,000	.85		
Per cent of owner-occupied housing units valued at $25,000 or more	—.89		
Substandard housing index	.73		
Per cent of male labor force 14 years and over in civilian labor force employed as white collar workers	—.94		
Per cent of female labor force 14 years and over in civilian labor force employed as white collar workers	—.81		
Per cent of families with female head of household of households with head under 65 years		.91	
Per cent of families below poverty level of total number of families	.83		
Number of housing structures built before 1940 as a percent of total occupied units	.65		
Persons 65 years and over and 18 years and younger below poverty level as a percent of total population	.86		
Per cent of husband-wife families of total number of families in households with head under 65 years	—.71		.64

is transformed into a new set of orthogonal vectors or principal components

$$(P_1, P_2, \ldots, P_m)$$

Those p principal components whose eigenvalues (λ_j) are 1.00 or larger are usually considered the basic dimensions in R or the fundamental attributes of the variables.

The eigenvalues in a principal components analysis are the latent roots of the m characteristic equations which set the determinant of R at zero:

$$(1) \qquad \begin{vmatrix} 1-\lambda_j & r_{12} & \cdots & r_{1m} \\ r_{21} & 1-\lambda_j & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & 1-\lambda_j \end{vmatrix} = 0$$

Given p_{ij} as the correlation between the ith standardized variable and the jth principal component (or as the ith coefficient of the jth component), a series of equations of the following form is developed:

$$(2) \qquad \begin{array}{l} p^2_{11} + p^2_{21} + \ldots + p^2_{m1} = \lambda_1 \\ p^2_{12} + p^2_{22} + \ldots + p^2_{m2} = \lambda_2 \\ \cdots\cdots\cdots\cdots \\ p^2_{1m} + p^2_{2m} + \ldots + p^2_{mm} = \lambda_m \end{array}$$

The function of the first principal component is to resolve a maximum amount of variance in R: succeeding principal components resolve as much as possible of the remaining variance through m iterations. Thus, it is necessary to maximize λ_1 initially and Larangian multipliers are used to obtain

$$(3) \qquad \begin{bmatrix} 1-\lambda & r_{12} & \cdots & r_{1m} \\ r_{21} & 1-\lambda & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & 1-\lambda \end{bmatrix} \begin{bmatrix} p_{11} \\ p_{21} \\ \cdot \\ p_{m1} \end{bmatrix} = 0$$

The first root is the eigenvalue corresponding to P_1 and the second through mth roots correspond to $P_2, P_3, \ldots, P_m$, respectively and are the largest roots of the residual correlation matrices $R_1, R_2, \ldots, R_{m-1}$, respectively. The coefficients ($p_{11}, p_{21}, \ldots, p_{m1}$) of P_1 are obtained by scaling its normalized eigenvector by λ_1:

$$(4) \qquad p_{i1} = a_{i1} (\lambda_1)^{1/2}$$

The coefficients of $P_2, P_3, \ldots, P_m$ are obtained by similar operations on the residual correlation matrices ($R\text{-}PP^t$) until

$$p = m$$

$$\sum^{m} \lambda_j = m$$

$$PP^t = R$$

It has already been noted that the second root of (3) is the eigenvalue corresponding to P_2, and so on.

Varimax Rotation. Labeling of the attributes of R is facilitated by transforming P to P′, using a varimax criterion in which P is rotated to that angle (Θ) in the plane which will maximize the variance of the principal components, subject to maintaining each variable's communality (h^2_i). This has the effect of increasing the absolute magnitude of those loadings (p_{ij}'s) whose absolute values are initially high and minimizing those whose absolute values are initially low. Generally, only those principal components of P whose eigenvalues are larger than 1.00 are rotated. Thus,

$$h^2_i = \sum^{p} p^2_{ij} \tag{5}$$

Specifically, Θ is the angle of rotation from which the transformation matrix

$$T = \begin{bmatrix} \cos \Theta & -\sin \Theta \\ \sin \Theta & \cos \Theta \end{bmatrix} \tag{6}$$

may be developed to maximize the function

$$V = m \sum^{p} \left[\sum^{m} (p_{ij}/h_i)^4 - \sum^{p} \left(\sum^{m} p^2_{ij}/h^2_i \right)^2 \right] \tag{7}$$

Scores on Principal Components. The m standardized variables may be condensed into p orthogonal standardized variables. Evidently, the most useful algorithm is

$$C = ZP\lambda^{-1} \tag{8}$$

where λ^{-1} is the inverse of the diagonal-eigenvalue matrix. Zero is of a larger order of magnitude than say, —1. In a spatial situation, c_{ij} is the standardized magnitude of attribute j at site i. Such scores are distributed as the standard normal deviate with mean zero and unit variance if the original data were normally distributed.

The primary function of the analysis was to elicit the basic attributes of the 42 transformed variables. Thus, a 42 × 42 correlation matrix was computed and collapsed into mutually exclusive attributes. Despite the fact that several eigenvalues were larger than one, it was deemed germane to examine only the first three principal components since they resolve, respectively, 50.5 percent, 17.2 percent, and 8.3 percent of the variance in the original correlation matrix, or collectively, 76.0 percent of its variance. The attributes were identified after varimax rotation and quantified according to the algorithm given in (8) for each neighborhood for mapping purposes.

Interpretation of Attributes. The first principal component (P_1) is interpreted as a positive indicator of *poverty*. Neighborhoods with high positive scores (c_{i1}) on this attribute would be expected to have low levels of achievement in such areas as education, income, quality and value of housing units. Such neighborhoods would typically have high birth and fertility rates, comparatively large numbers of families and individuals living below poverty levels, low levels of home ownership by occupants, and fewer people employed in the so-called "white collar" category than neighborhoods having near-zero or negative scores on this indicator.

The second principal component (P_2) is deemed to be indicative of the *youthfulness* of the population. Neighborhoods with high positive scores on this attribute would be expected to have low median ages for both males and females, comparatively large proportions of the population younger than the age of 20, small proportions older than 60, and associated low death rates.

The third principal component (P_3) is identified as an *ethnicity* attribute. Neighborhoods with high positive scores on this attribute would be expected to have comparatively large proportions of the population classified as foreign stock as well as small proportions listed as Black. Positive scores would also be indicative of proportionately large numbers of males in the labor force, high proportions of the population completing high school, and most households represented by both husbands and wives. Such characteristics are those which are traditionally associated with the stereotyped ethnic White neighborhood.

Maps of Scores on Principal Components

As the intensity of the shading increases, the presence of the attribute measured by the principal component increases relative to areas of less intense shading. No absolute values are attached to either rates of occurrence of an attribute within an area or to rates of change between areas. In other words, comparisons between areas are of the "greater than", "less than", or "approximately equal to" nature.

The map of scores on the first principal component (c_{i1}) depicts a readily discernible gradient away from the center of the city: high positive scores on the poverty attribute of the data are centered on Halyard Park and Garfield, economically and socially depressed sections of the county. Low and negative scores occur as one moves away from the downtown area (Figure 2, Table 2).

The map of scores on the second principal component (c_{i2}) indicates that the youngest populations are in the "core" of the city (e.g., Garfield, Halyard Park, and Midtown); in the northwestern

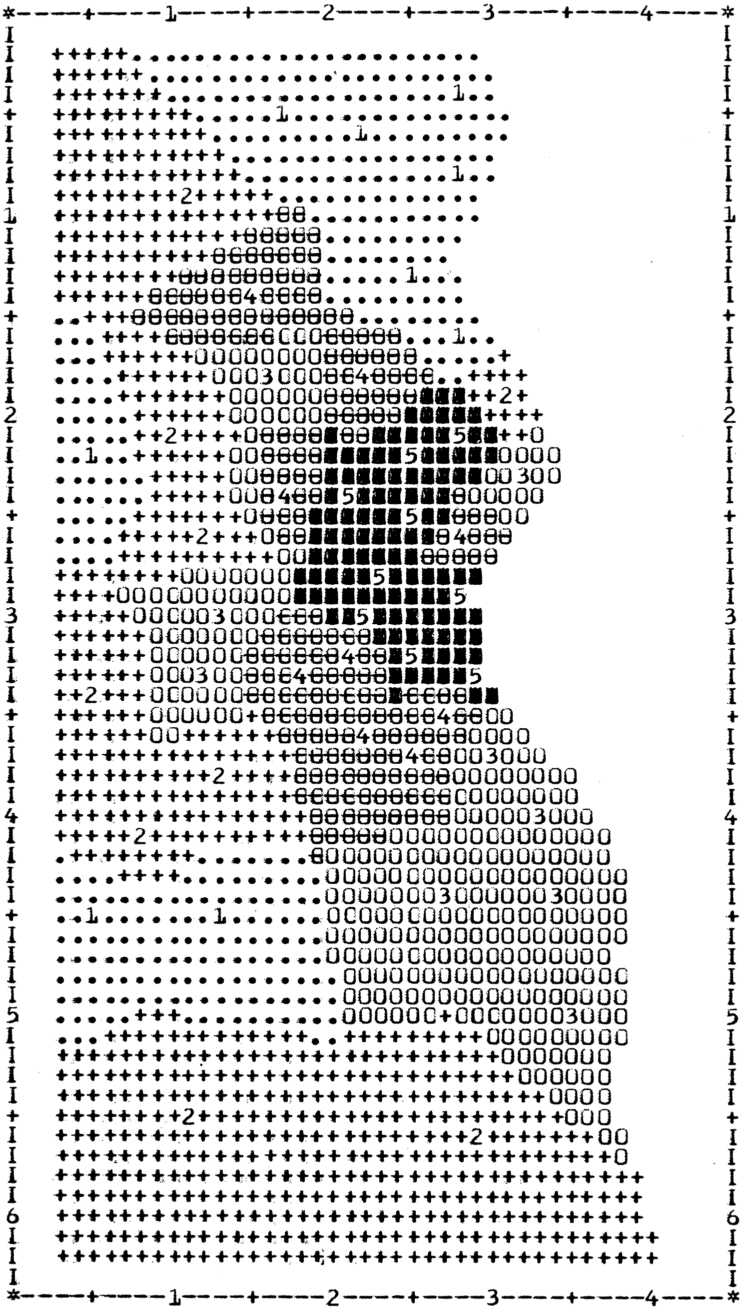

FIGURE 2. Distribution of Scores on the First Socioeconomic Attribute (Poverty)

TABLE 2. RANK ORDER OF NEIGHBORHOODS ON THE FIRST SOCIOECONOMIC ATTRIBUTE (POVERTY) MAP CLASSES—RANKED HIGHEST TO LOWEST

Halyard Park	West Milwaukee	Franklin
Garfield	Old West Allis	Shorewood
Midtown	Johnson's Woods	Wauwatosa Avenue
Walker's Point	Bay View	Greenfield
The Valley	Cudahy	Wauwatosa East
Grand Avenue	Lakeside	Wauwatosa West
Riverside West	North Milwaukee	Glendale
Kosciuszko	St. Francis	Greendale
Juneautown	South Milwaukee	Hales Corners
Lincoln Creek	Lake	Brown Deer
Muskego Avenue	Oak Creek	Whitefish Bay
Tippecanoe	Granville	River Hills
Silver Spring	West Allis Addition	Fox Point
Layton Park	Jackson Park	Bay Side
Sherman Park		

portion of Milwaukee County (Granville, Silver Spring, and Brown Deer); and in the southern portion (Oak Creek, Franklin, and Greendale) (Figure 3, Table 3).

The map of scores on ethnicity (c_{i3}) shows that high degrees of this attribute are concentrated almost exclusively to the south of the Menominee River. Highest scores are found in such neighborhoods as The Valley, Cudahy, St. Francis, Tippecanoe, Lake, Jackson Park, and Kosciuszko. Low and negative scores evidently indicate one of two things; either a lack of people classified as of foreign stock or the presence of large numbers of Blacks in the population. This accounts for the fact that such neighborhoods as Whitefish Bay and Halyard Park have similar scores on this component (Figure 4, Table 4).

TABLE 3. RANK ORDER OF NEIGHBORHOODS ON THE SECOND SOCIOECONOMIC ATTRIBUTE (YOUTHFULNESS) MAP CLASSES—RANKED HIGHEST TO LOWEST

Garfield	Lincoln Creek	Muskego Avenue
Greendale	West Allis Addition	Old West Allis
Oak Creek	St. Francis	Walker's Point
Granville	Bayside	Tippecanoe
Halyard Park	Wauwatosa West	Johnson's Woods
Franklin	Fox Point	Wauwatosa Avenue
Brown Deer	Whitefish Bay	North Milwaukee
Silver Spring	The Valley	Wauwatosa East
Midtown	Glendale	Sherman Park
Lake	River Hills	Shorewood
Greenfield	Bay View	Grand Avenue
Hales Corners	Layton Park	Lakeside
South Milwaukee	Riverside West	West Milwaukee
Jackson Park	Kosciuszko	Juneautown
Cudahy		

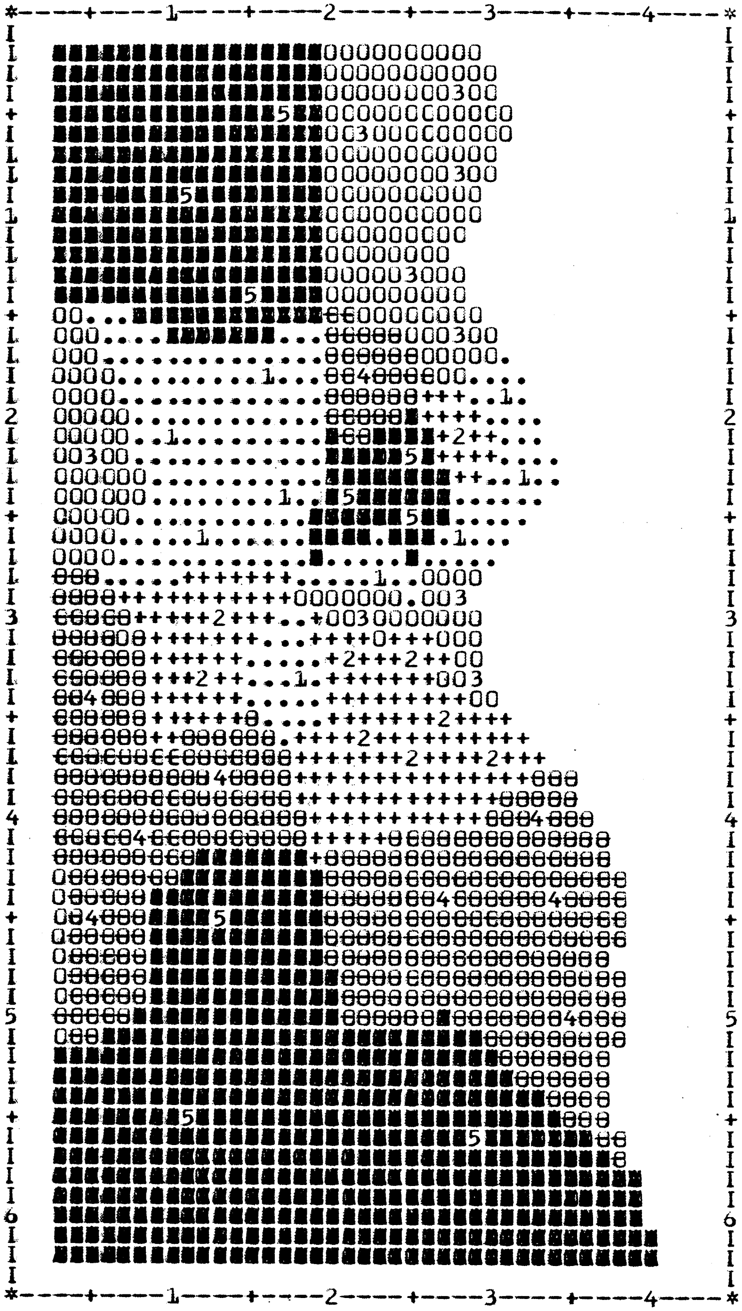

FIGURE 3. Distribution of Scores on the Second Socioeconomic Attribute (Youthfulness)

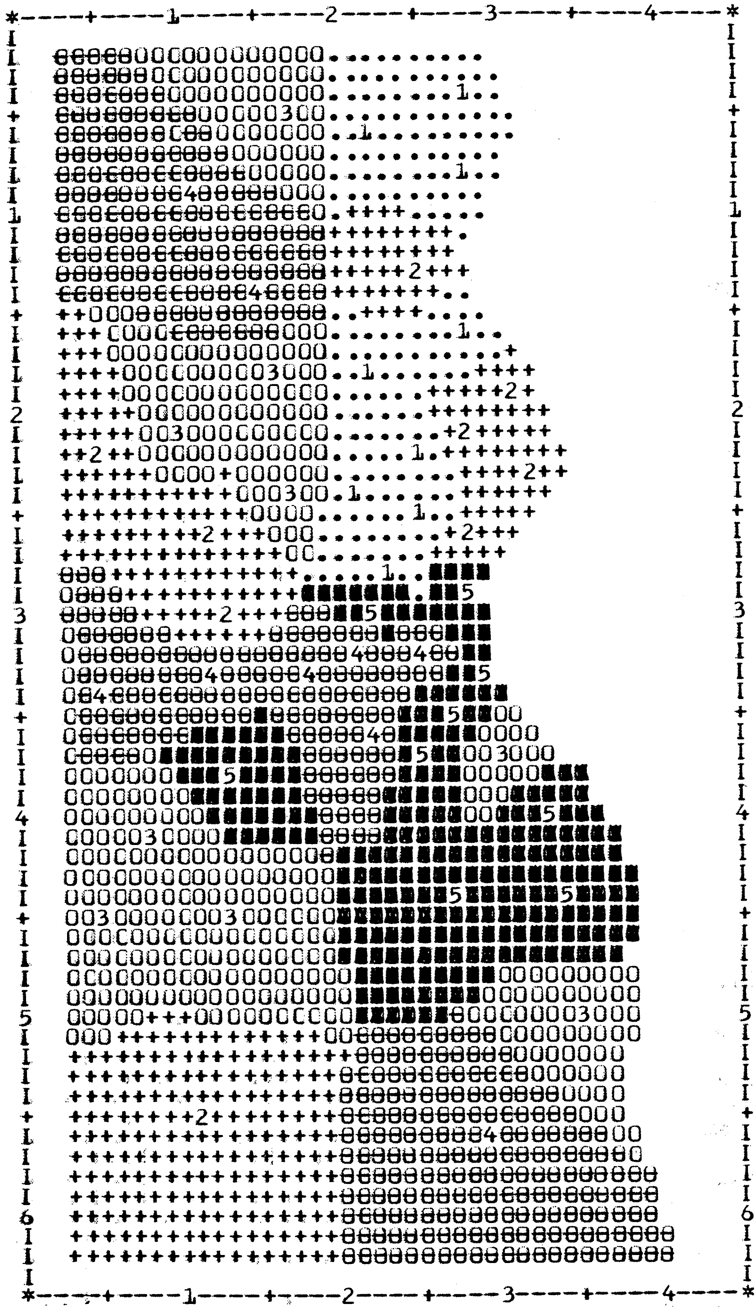

FIGURE 4. Distribution of Scores on the Third Socioeconomic Attribute (Ethnicity)

TABLE 4. RANK ORDER OF NEIGHBORHOODS ON THE THIRD SOCIOECONOMIC ATTRIBUTE (ETHNICITY) MAP CLASSES—RANKED HIGHEST TO LOWEST

The Valley	Walker's Point	Lakeside
Cudahy	Bay View	Glendale
St. Francis	Greenfield	Juneautown
Tippecanoe	South Milwaukee	Wauwatosa East
Lake	Hales Corners	Shorewood
Jackson	Brown Deer	Grand Avenue
Kosciuszko	Wauwatosa Avenue	Lincoln Creek
West Milwaukee	Franklin	Midtown
Muskego Avenue	Sherman Park	Whitefish Bay
Layton Park	North Milwaukee	Garfield
Oak Creek	Greendale	Fox Point
Silver Spring	Johnson's Woods	Bayside
Granville	Wauwatosa West	River Hills
Old West Allis	Riverside West	Halyard Park
West Allis Addition		

Quality of Life Index

A synthetic quality of life index was constructed using a linear combination of each neighborhood's scores on the three principal components, i.e.,

$$QL_i = -\lambda_1 c_{i1} + \lambda_2 c_{i2} + \lambda_3 c_{i3} \quad (9)$$

Since the eigenvalues are the coefficients of the scores, each component contributes to the magnitude of the index in an amount directly proportional to the amount of the variance which it resolved. Thus, the index is heavily weighted by the first principal component, whose coefficient is given a negative sign since it measures a poverty attribute. Nevertheless, interesting patterns emerge when the index is mapped (Figure 5, Table 5). As with the maps of component scores, only comparisons of the "greater than", "less

TABLE 5. RANK ORDER OF NEIGHBORHOODS ON THE QUALITY OF LIFE INDEX MAP CLASSES—RANKED HIGHEST TO LOWEST

Fox Point	West Allis Addition	Cudahy
River Hills	Sherman Park	Tippecanoe
Bay Side	Johnson's Woods	West Milwaukee
Whitefish Bay	Jackson Park	Grand Avenue
Glendale	Bay View	Silver Spring
Wauwatosa East	Franklin	Muskego Avenue
Shorewood	Juneautown	Lincoln Creek
Wauwatosa West	Old West Allis	Kosciuszko
Wauwatosa Avenue	South Milwaukee	Riverside West
Hales Corners	St. Francis	Walker's Point
Lakeside	Layton Park	The Valley
Brown Deer	Lake	Midtown
Greendale	Granville	Garfield
North Milwaukee	Oak Creek	Halyard Park
Greenfield		

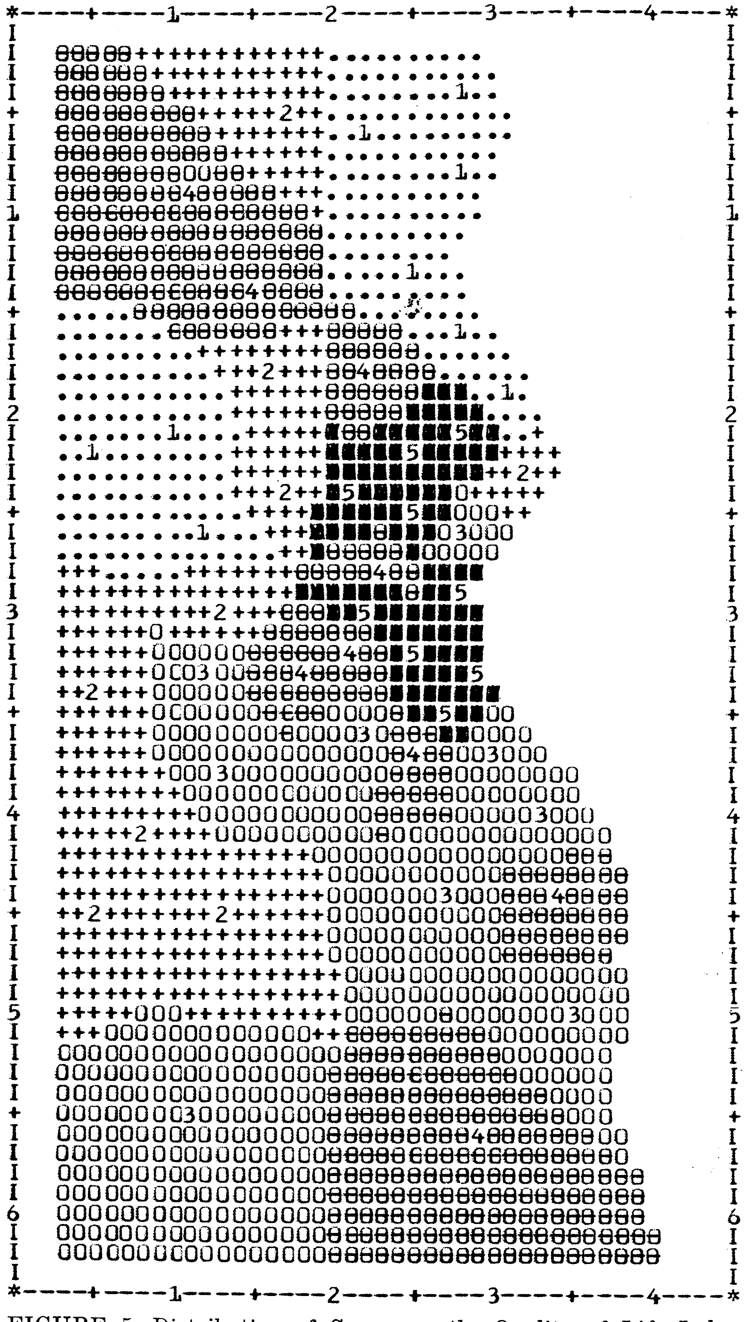

FIGURE 5. Distribution of Scores on the Quality of Life Index

than", or "approximately equal to" nature are possible. Those neighborhoods which might be deemed least advantageous or most susceptible to urban strain from the socioeconomic standpoint form two parcels separated by the commercial development of the Grand Avenue neighborhood (Milwaukee's most intensively commercial area). The northern parcel is comprised of Halyard Park, Garfield, Midtown, and Riverside West. The southern parcel consists of The Valley, Kosciuszko, and Walker's Point. Those neighborhoods for whom quality of life is evidently the highest also form two essentially contiguous groups; Wauwatosa Avenue, Wauwatosa East, and Wauwatosa West in the west-central section of the county and Shorewood, Glendale, Whitefish Bay, Bay Side, River Hills, and Fox Point in the northeastern section.

CONCLUSIONS

This study has shown in a quantitative manner that there is considerable spatial inequality in the quality of life in Milwaukee County—that there is a large amount of neighborhood to neighborhood variation in its socioeconomic health. This is a condition which is suggestive of potential urban strain, or as Harvey (1972) has noted, tension between the spatial organization of the present society and that spatial organization which might be demanded by a new social order. One might advocate that such a spatial organization must, in an economic and social context, generate a social surplus product if urbanism is to survive. Hence, this study should not only provide a data base for both public and private agencies for research and planning, but also serve as a vehicle to promote intensive social change in those areas of Milwaukee County deemed lacking in the socioeconomic health or quality of life enjoyed by other neighborhoods.

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PRIMES AND FAREY SEQUENCES

Arthur Marshall
Madison

This paper is aimed at helping teachers of pre-college or freshman mathematics to demonstrate how prime numbers arise in the natural ("counting") number system and how prime numbers can be "predicted" from examination of numbers less than themselves.

We will show that primes are the result of adding the numerator and denominator of certain "Farey Sequences" fractions (a/b with $0 < a < b$, $b \geqq 2$, and $(a, b) = 1$), starting with *1/2*. (We have just used the greatest-common-divisor symbol of number theory literature.)

All letters stand for positive integers (sometimes called natural numbers or counting numbers).

THEOREM: If $(a, b) = 1$, then $(a, a + b) = 1$ and $(b, a + b) = 1$. Conversely, if $0 < a < n/2$, and $(a, n) = 1$, then $(a, n - a) = 1$ with $a/(n - a) < 1$, and $(n - a, n) = 1$, with $(n - a)/n < 1$.

PROOF: If a $= 1$, the theorem is obvious.

If a > 1, then (using congruence notation of elementary number theory) $a \equiv 0 \pmod{p}$, where p is any prime dividing a. Because $(a, b) = 1$, $b \not\equiv 0 \pmod{p}$, then, by addition of congruences $(a + b) \not\equiv 0 \pmod{p}$, and the first assertion of the first part of the theorem is proved. We follow an analogous procedure for q, any prime dividing b, and the second assertion of the first part is proved.

To prove the converse, we note that p, any prime dividing a, cannot, by hypothesis divide n. Then $(n - a) \equiv n \not\equiv 0 \pmod{p}$ and the first statement of the converse is proved. To prove the second statement of the converse, we note that q, any prime dividing n, cannot, by hypothesis divide $(n - a)$, because $(n - a) \equiv -a \not\equiv \pmod{q}$, and that completes proof of the theorem.

COROLLARY 1. All fractions in Farey sequences, lying between 0 and 1, can be obtained by successive additions of numerators and denominators, beginning with ½, to obtain new fraction denominators and taking each summand numerator and denominator as numerators over the new denominators. (The proof is immediate from the theorem.)

We now use the usual Greek symbol ϕ (phi) for the Euler totient: $\phi(n)$ is the count of numbers less than n which have no common divisor with n greater than 1.

COROLLARY 2. For n > 2, there exist $\phi(n)/2$ Farey fractions of the type $a/(n - a)$ with denominators less than or equal to $(n - 1)$.

PROOF. Immediate from Corollary 1.

COROLLARY 3. For $n > 2$, , n is prime if, and only if, there exist $(n - 1)/2$ Farey fractions of the type $a/(n - a)$ with denominators less than or equal to (n — 1).

PROOF. By definition, n is prime if, and only if, n has just two divisors: 1 and n, where $n > 1$. If there exist fewer than $(n - 1)/2$ Farey fractions of the type $a/(n - a)$, with denominators less than or equal to $(n - 1)$, then n has at least one divisor lying between 1 and n. If there exist just $(n - 1)/2$ Farey fractions of the above type, our definition of primes is satisfied.

ALTERNATIVE PROOF. Directly from Corollary 2.

COROLLARY 4. There exist exactly $(n - 1)$ Farey fractions with denominator n, if, and only if, n is prime.

PROOF. For $n = 2$, this is immediately verified. For $n > 2$, this follows immediately from Corollary 3 and our theorem.

ALTERNATIVE PROOF. Directly from our definition of prime numbers.

The writer believes quick primality tests and factoring algorithm programs can be written from this theorem and its corollaries, but will leave that to computer specialists. Any such programs, of course, would have to be competitive with those arising from Problem E 2355 [1] and the more sophisticated programs discussed by Collins [2].

1. Problem E 2355, Amer. Math. Monthly, 80:560–561. 1973. (Solution by R. J. EVANS. Proposed by A. MARSHALL.)
2. G. E. COLLINS. Computer algebra of polynomials and rational functions. Amer. Math. Monthly, 80:725–755, 1973.

Correction

Congruence symbol "$=$" and non-congruence symbol "$\neq$" in the text of this paper should have *three bars*, but the correct type items were not available.

PRELIMINARY REPORTS ON THE FLORA OF WISCONSIN NO. 64. ADOXACEAE—MOSCHATEL FAMILY

Theodore S. Cochrane
University Wisconsin—Madison
and
Peter J. Salamun
University Wisconsin—Milwaukee

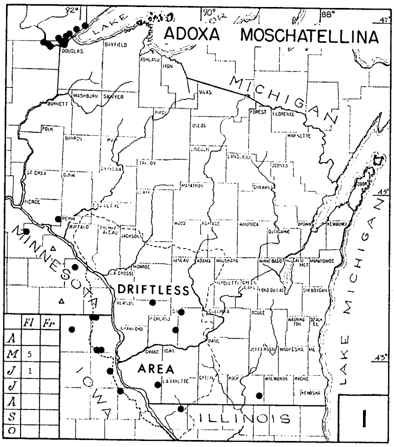
The Adoxaceae consists of a single worldwide, north temperate species which occurs rarely in the United States, including Wisconsin. The family is usually included in the Rubiales, although some authorities consider it to be more closely related to the Saxifragaceae or possibly the Ranunculaceae. According to modern opinion *Adoxa* is a specialized offshoot of the Caprifoliaceae (Cronquist 1968), the family in which it was listed in an earlier Wisconsin report (Wade and Wade 1940).

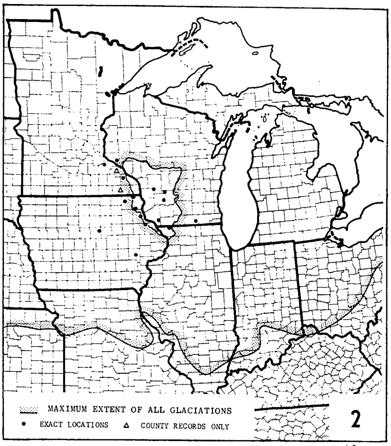
The distribution of the species, habitat information and dates of flowering and fruiting were compiled from specimens in the herbaria of the University of Wisconsin—Madison (WIS), University of Wisconsin—Milwaukee (UWM), University of Wisconsin Center—Rock County (ULJ), Milwaukee Public Museum (MIL), University of Iowa (IA), University of Michigan (MICH) and the University of Minnesota (MIN). Each dot on the map indicates a specific location where a specimen was collected, while triangles represent county records taken from the literature. Additional records from Hartley's unpublished "Flora of the Driftless Area" (1962), Lakela's *Flora of Northeastern Minnesota* (1965) and Morley's *Spring Flora of Minnesota* (1966) have been included. The numbers within the squares in the lower left-hand corner of Map 1 indicate the number of Wisconsin specimens noted that were flowering or fruiting in the respective months. Specimens in vegetative condition, in bud or with immature or dispersed fruits are not included.

Grateful acknowledgement is made to the curators of the above herbaria for loans of specimens and especially to Dr. Hugh H. Iltis for discussing the material contained in this paper with the first author.

ADOXACEAE J. G. AGARDH MOSCHATEL FAMILY

A monotypic family of circumboreal distribution, extending southward in North America to northern New York, northwestern Illinois, South Dakota and in the Rocky Mountains to New Mexico.





1. ADOXA L. MOSCHATEL, MUSKROOT

1. ADOXA MOSCHATELLINA L. Maps 1, 2.
Moschatel, Muskroot

Low delicate perennial 5–15 (–20) cm high with musk-scented, white-scaly rhizomes and an erect, simple, glabrous stem. Basal leaves 1–3, long-petiolate, ternately compound, the ovate to obovate or orbicular leaflets yellow-green, membranous, coarse-toothed to 3-parted, obtuse, glandular-mucronate. Cauline leaves an opposite pair, 3-parted, smaller, less divided and shorter petioled than the basal leaves. *Inflorescence an angular, cymose head* 6–8 mm in diam, the slender peduncle often overtopped by the basal leaves. Flowers small, 3–8, usually 5, regular or nearly so, perfect, sympetalous. Calyx 2-4-lobed, persistent in fruit. *Corolla 4-6-lobed, yellow-green, rotate,* the lobes 1.7–3 mm long. *Stamens* twice as many as the corolla lobes, *in epipetalous pairs on the corolla tube and alternate with its lobes, separate or partly united; anthers 1-celled. Ovary semi-inferior, 3-5-celled;* style short, deeply 3-5-parted, the stigmas minute. Fruit a dry drupelet, green; nutlets (1–) 3–5, lenticular, cartilaginous, 2.9 mm in diam. $2n = 36$ (54, Japan).

Rare and very local in cool moist woods under coniferous trees on bare or mossy ground, sometimes in leaf mold, on shaded, usually north-facing sandstone or limestone bluffs and talus slopes, rarely in mesic hardwoods. Since *Adoxa* is of unusual biogeographic interest, all Wisconsin collections are cited herewith: Grant Co.: Platteville (*Smithyman s.n.*, 4 May 1896, MIL, WIS). [Pierce Co.:] near Plum City, between Durand and Ellsworth (*Butters 4434,* 1 June 1924, MIN, UWM). Richland Co.: W-facing sandstone cliff near Butternut School, sec. 34, T11N, R2E, 4 mi. N of Ithaca (*Fassett 26325,* 2 June 1946, WIS). Rock Co.: limestone outcrops and damp shaded slopes on S bank of Turtle Creek, with *Tilia americana, Carex albursina, Erythronium albidum, Claytonia virginica, Isopyrum biternatum, Dicentra canadensis, D. cucullaria, Dentaria laciniata, Mitella diphylla,* etc., sec. 28, T3N [sic, for T2N], R14E [3 mi. NE of Clinton] (*Musselman 3487,* 2 May 1970, ULJ); same location (*Musselman 3505,* 6 May 1970, ULJ, UWM). Sauk Co.: small patch in liverwort and moss mat on moist N-facing sandstone ledge along Baraboo River, shaded by *Tsuga canadensis* and *Betula alleghaniensis,* sec. 20, T13N, R3E [1 mi. NW of La Valle] (*Nee & Peet 2234,* 18 July 1969, WIS); same location (*Cochrane & Nee 5639,* 31 July 1973, WIS). Vernon Co.: Ontario (*Fassett 17963,* June 1936, WIS); talus at base of shaded sandstone ledge along Kickapoo River, Wildcat Mt. State Park, sec. 14, T14N, R2W (*Hartley & Morrissey 9146,* 14 May 1960, IA, WIS); under conifers just above sandstone ledges along Hemlock Trail, S end of Wildcat Mt. State Park (*Salamun & Matthiae 2879,* 2 June 1970, UWM). This species, not uncommon in northeastern Minnesota, should be sought in the Lake Superior area of Wisconsin. Flowering 2 May to 1 June; fruiting June to July.

The terminal flower is usually tetramerous, with 4 styles and 8 anthers, while the lateral ones are pentamerous or hexamerous, with 5 or 6 styles and 10 or 12 anthers. Each pair of stamens probably represents a single one which is divided nearly to the base of the filament, with each segment bearing a half-anther. The possibility that the calyx and corolla may constitute an involucre and calyx contributes to the uncertain relationships of this family (*cf.* Sprague 1927).

In an attempt to relocate *Adoxa moschatellina* the senior author, accompanied by Michael Nee, visited on July 31, 1973, two waterworn, upper Cambrian sandstone cliffs on which the species was known to occur. The most conspicuous feature of such cliffs, which are common in the Driftless Area, is the presence on many of them of "relict" stands of conifers. These stands are intriguing, for they are composed of species which are chiefly northern in distribution and are rare or unknown in southern Wisconsin outside of that famous region. The Butternut School station has long been known to be botanically rich, ever since Norman C. Fassett found there both *Adoxa* and *Ledum groenlandicum.* Had he ventured a little farther eastward to the north-facing portion of the cliff, unreachable from below due to undercutting by Willow Creek, Fassett would have encountered an idyllic cove on whose steep cool slopes and cliffs, shaded by yellow birch and white pine, grow numerous mosses and liverworts, including the rare sword moss *(Bryoxiphium norvegicum)* and a six-meter-square patch of *Sphagnum.* The associated understory consists of a large number of typically northern species: *Equisetum scirpoides, Lycopodium selago, L. lucidulum, L. obscurum, Coptis groenlandica, Cornus canadensis, Chimaphila umbellata, Gaultheria procumbens,* and *Mitchella repens.* The *Adoxa* was not found in 1973, and it is not known whether or not colonies persist on this mile-long cliff, which botanically must be among the most remarkable ones in the Driftless Area.

Mr. Nee discovered a population of *Adoxa* on the west end of Horse Bluff, near LaValle in Sauk County, at the time of his first visit. Although the plants are inconspicuous, the distinctive scintillating quality of their pale leaves and the absence of nearby vegetation enabled us to find them again after a brief search. There are only three small colonies, consisting of 21, 39, and 61 plants and growing on narrow ledges one to two and one-half meters long along the base of a small cove formed by low cliffs four meters high. These sandstone ledges are relatively free of vegetation except for mosses, the liverwort *Conocephalum conicum,* and a few plants of *Pilea.* The shallow mineral soil in which the plants grow has an acid reaction, with a pH of 5.2. A fine stand of hemlock and yellow birch occupies the steep rocky north-facing slopes. The shrubs found in the stand show a resemblance to those of the northern forests and include *Taxus canadensis, Acer spicatum,* and *Sambucus pubens.* The conspicuous herbs in the nearby understory are *Laportea canadensis, Athyrium thelypteroides,* and *Dryopteris austriaca* var. *intermedia.* Certainly equivalent habitats are frequent in the Driftless Area, but most of them are not occupied by *Adoxa moschatellina.*

The range descriptions given for *Adoxa* in the regional manuals are incomplete, for Fernald (1950) omitted its occurrence in northern Illinois as did Gleason (1952) in northern New York. In southern Wisconsin and northwestern Illinois (that state's only station in Apple River Canyon) it is at the southeasternmost limit of its range, except for two reports from Delaware Co., New York (Taylor 1913; Brooks 1960). House (1924, p. 655) suggested that the one station known to him was an introduction, but surely plants of this isolated locality high in the Catskills at 1,400 feet represent native populations. The geographic distribution of *Adoxa* suggests that in the Midwest it is a western immigrant that crossed the Bering Straits and barely reached Wisconsin. With the exception of New York it is totally lacking from eastern North America.

In the Midwest the distribution of *Adoxa* is correlated with, but not restricted to, the "Driftless Area" of Wisconsin and adjoining Minnesota, Iowa and Illinois (Map 2), a coincidence probably due to the presence here of suitable habitats rather than to this famous region's being the plant's Pleistocene refugium. In Europe, as in America, the species occupies various highly disjunct locations in the Caucasus and in Turkey, Italy, Spain and Morocco, indicating that it is either easily dispersed or that it has survived successfully as a relict from a cooler, postglacial period. It is important to note that 1) it grows in clearly glaciated territory in Wisconsin, Minnesota and east-central Iowa [but probably not southwestern Iowa as shown by Hultén (1970, Map 104)], 2) other subarctic or boreal species, namely *Primula mistassinica* (*cf.* Iltis & Shaughnessy 1960), *Rhododendron lapponicum, Chrysoplenium ioense (C. tetrandrum)* and *Gymnocarpium robertianum* also occur in the Midwest in the region of the "Driftless Area," 3) ferns, primroses and saxifrages have small propagules, making long-distance, postglacial dispersal possible and 4) the microenvironments of damp, cool, rocky habitats would remain relatively little influenced by postglacial vegetational changes occurring in the region, permitting survival of the periglacial flora.

It is probable, on ecologic as well as geographic grounds, that *Adoxa* is an old species whose present-day disjunct range, rather than being the result of ease of dispersal and pioneer propensities, is due likely to relictual survival in isolated microhabitats from a cooler, interglacial or postglacial period. While now thought to have been glaciated, the "Driftless Area" was never covered completely by the later Pleistocene ice sheets. Certainly it was available for plant occupation since early Wisconsinan time, if mostly overlain by ice of the Altonian Substage as believed by Black (1962), and probably since the Nebraskan Stage. As developed by Butters and Abbe (1953) and recognized by Cushing (1965), disjunct rarities, whether boreal *(Adoxa)*, "cordilleran" *(Mertensia paniculata)*, or southern *(Spiraea tomentosa* var. *rosea)*, should not be cited (Fassett 1931; Schuster 1958; Curtis 1959) as members of a preglacial flora that survived continental glaciation in a "Driftless Area" nunatak, nor should they be used even to imply that the "Driftless Area" was a preglacial plant refugium.

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PRELIMINARY REPORTS ON THE FLORA OF WISCONSIN NO. 65. DIPSACACEAE—TEASEL FAMILY

Peter J. Salamun
University Wisconsin—Milwaukee
and
Theodore S. Cochrane
University Wisconsin—Madison

This study of the Dipsacaceae, represented in Wisconsin by four Eurasian species which occasionally escape from cultivation, is based on collections deposited in the herbaria of the University of Wisconsin (WIS), University of Wisconsin—Milwaukee (UWM), Milwaukee Public Museum (MIL), University of Minnesota (MIN) and Wisconsin State University—Oshkosh (WSO). We thank the curators of these herbaria for loans of specimens, and we gratefully acknowledge the cooperation of Mr. Floyd Swink of the Morton Arboretum, Lisle, Illinois, who supplied data for an additional map record.

Dots on the maps indicate exact locations where specimens have been collected; triangles represent county records added from Swink's *Plants of the Chicago Region* (1969). The numbers within the map corner inserts show the amount of flowering and fruiting material noted and indicate when the species may be expected to flower or fruit in Wisconsin. Specimens with vegetative growth only, buds, or with immature or dispersed fruits are not included. The nomenclature and descriptive features generally follow Gleason (1952) and Fernald (1950); however, more recent taxonomic treatments of certain taxa are discussed in the text or cited in the bibliography.

DIPSACACEAE A. L. DE JUSSIEU TEASEL FAMILY

Annual, biennial or perennial herbs with opposite or whorled, exstipulate leaves and *inflorescences of dense involucrate heads or rarely short spikes.* Flowers perfect, epigynous, more or less irregular, *subtended by a calyx-like involucel (epicalyx) which closely subtends the ovary and often also a receptacular bract. Calyx minute,* cupulate, a 4–5-toothed or divided into 5–10 conspicuous pappus-like segments. Corolla tubular, 4–5-lobed. Stamens (2–3) 4, distinct, epipetalous near the base of the corolla tube and alternate with its lobes, exserted, the anthers 2-celled, versatile, dehiscing longitudinally. Ovary inferior, 1-celled, 2-carpellate but only one developing, with a solitary pendulous ovule; style filiform, the stigma simple or 2-lobed. *Fruit an achene enclosed within the gamophyllous involucel* and often crowned by the persistent calyx. Embryo straight, the endosperm fleshy.

An Old World family of 8–12 genera and 250 species, mostly Mediterranean, distinguished from the related Valerianaceae and Caprifoliaceae by the unilocular ovary and the capitate inflorescence surrounded by an involucre of bracts, and from the Compositae by the distinct, exserted stamens, the pendulous ovule and the fruit enclosed by an involucel. The "heads" are cymose aggregations of 1-flowered heads whose flowers open first near the center of the inflorescence, then simultaneously toward both the apex and the base.

KEY TO GENERA

A. Plants prickly; heads ovoid to subcylindric, the involucral bracts upcurved, and spine-tipped, 2–15 cm long; corollas all alike; calyx 4-toothed or -lobed. ____________1. DIPSACUS.

AA. Plants not prickly; heads convex, hemispheric or subglobose, the involucral bracts ascending to reflexed, not spine-tipped, 0.5–1.5 cm long; corollas of marginal flowers expanded and ray-like.

B. Receptacle with chaffy bracts; involucral bracts rigid and brown, imbricate in several rows; corollas cream to yellow; calyx teeth ca. 25. _________2. CEPHALARIA.

BB. Receptacle with dense hairs; involucral bracts herbaceous and green, in 1 or 2 definite rows; corollas lilac-purple; calyx awns 8–16. ______________3. KNAUTIA.

1. DIPSACUS L. Teasel

Tall biennial or perennial herbs with *stout prickly or rough-hairy stems* from taproots and opposite, sessile or connate, toothed or pinnatifid leaves. Heads dense, ovoid to cylindric, with *rigid, long-tapering receptacular bracts and spine-tipped involucral bracts.* Flowers 8–15 mm long, the *marginal ones not enlarged, subtended by 4-angled, obscurely 4-toothed calyx-like involucels.* Calyx tube 4-angled, adherent to the ovary, the *limb cupulate, 4-toothed or -lobed, ciliate but without appendages.* Corolla funnelform, nearly regularly 4-lobed, with whitish tube and pale purple lobes. Stamens 4. Ovary 1-celled; style filiform, the stigma oblique, entire. Achenes 8-ribbed, enclosed by the involucel.

Native to Eurasia and North and East Africa, with 3 of the 12 species adventive or naturalized in North America.

KEY TO SPECIES

A. Cauline leaves lanceolate to oblong-lanceolate, toothed and often prickly on the margins, becoming entire upward and commonly connate at the base. ---------1. *D. FULLONUM.*

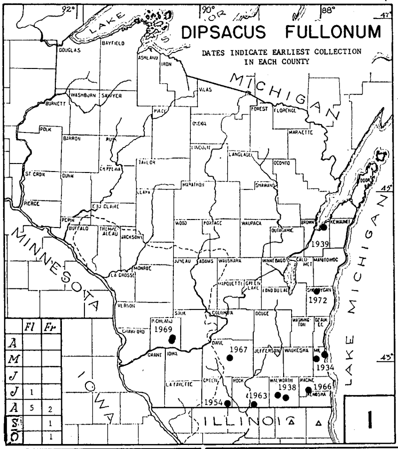
AA. Cauline leaves pinnatifid or bipinnatifid, the margins more or less bristly-ciliate, their bases confluent and forming a cup. ---------------------------------2. *D. LACINIATUS.*

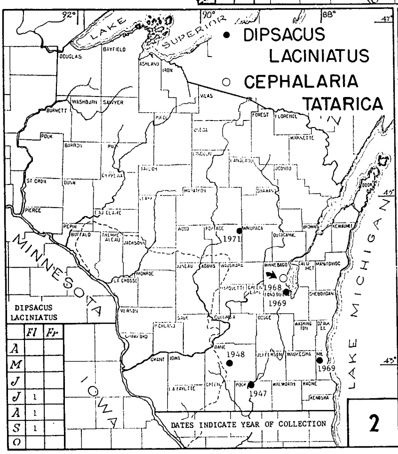
1. DIPSACUS FULLONUM L. Map 1.
Wild Teasel, Common Teasel
Dipsacus sylvestris Hudson of American authors
Dipsacus fullonum L. ssp. *sylvestris* Claph.

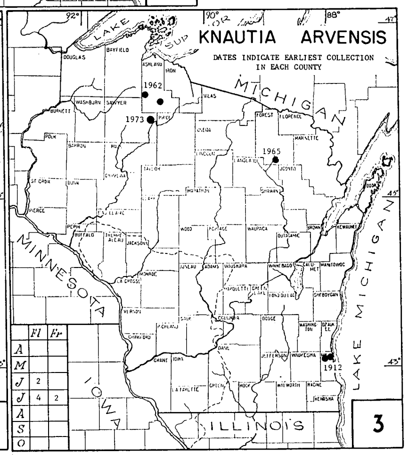
Stout biennial 0.5–2 (3) m tall, the stem striate-angled, prickly. Basal leaves oblong to oblanceolate, arcuate, usually dying early in the second season. *Cauline leaves sessile, lanceolate to oblong-lanceolate,* to 3 (4) dm long, 4–10 cm wide, *crenate-serrate, often prickly-dentate on the margins and the midrib beneath,* becoming entire upward and *commonly connate at the base.* Heads ovoid to subcylindric, 3–10 cm high, 3–5 cm wide, on long naked peduncles; *receptacular bracts oblong, abruptly tapering to stiff straight barbed awns exceeding the flowers; involucral bracts linear-elongate, subulate, upcurved, some of them equaling or exceeding the heads,* 2–15 cm long, 2–5 mm wide. Calyx cup 1 mm high, silky-pubescent. Corolla 8–12 mm long, the tube pilose, lavender (or rarely white in forma ALBIDUS Steyerm.). Achenes 4–7 mm long. $2n = 16, 18$.

Native to Europe, North Africa, and the Near East, now widely naturalized throughout the United States and southern Canada, in Wisconsin occasionally cultivated for ornament and adventive or locally established along open roadsides and abandoned railroad embankments, in fallow fields, low pastures, such as along Willow Creek, Richland Co., with *Verbena hastata, Cirsium vulgare* and *Helenium autumnale* (*Nee 2681, 2743,* WIS), and persisting in trash dumps and waste heaps near cemeteries and greenhouses. Flowering July to September; fruiting September to October.

Fuller's Teasel, *Dipsacus sativus* (L.) Honckney *(D. fullonum* L. of many authors), differs from the above species in having slightly stouter and strongly recurved receptacular bracts nearly equaling the flowers, spreading involucral bracts not surpassing the head and corollas 10–14 mm long. Grown for the "teasels" or mature heads which are used in raising the nap (fulling) on woolen cloth, it occasionally escapes in the vicinity of textile mills. However, it has not been collected in Wisconsin. Several authors







have implied that the cultivated teasel with the recurved receptacular bracts has been derived from the wild *D. fullonum* with erect bracts. Hegi (1908) suggested instead that the cultivar was selected originally from *D. ferox* Lois., a wild species of France, Italy and Spain. The nomenclature of these two taxa follows that adopted by Ferguson and Brizicky (1965).

2. DIPSACUS LACINIATUS L. Map 2, dots.
Cut-leaved Teasel

Much resembling *D. fullonum*, but *leaves irregularly and coarsely pinnately-cleft*, the margins bristly-ciliate, and the *bases of the paired cauline leaves confluent to form prominent cups*. Involucral bracts lanceolate to linear-lanceolate, 2–8 cm long, 3–7 mm wide, 6–12 times as long as wide, *shorter than to barely exceeding the mature head.* $2n = 16, 18$.

Native to southern Europe, southwestern Russia and Persia, rarely adventive in North America, rare in south- and east-central Wisconsin along roadsides, in disturbed marshes and in cemeteries and dumps. This species, much rarer than the last, has been previously reported in the state only from Rock Co. (Musselman et al., p. 187. 1971). The specimen cited there is *Dipsacus fullonum,* but other authentic collections have been seen from Rock and several other counties: Dane Co.: Madison, waste heap, Holy Cross Cemetery, Franklin Ave. and Regent St. (*Bergseng s.n.,* 30 Jul 1948, WIS). Fond du Lac Co.: marsh S of Soo Line RR, sec. 6, T16N, R17E (*Furstenberg 151,* 28 Nov 1969, WSO). Milwaukee Co.: Milwaukee, 2 plants in field, Wanderer's Rest Cemetery (*Niss s.n.,* 27 Sep 1969, WIS). Rock Co.: roadside, Hwy. H, 1 mi. E of Indianford (*Greene s.n.,* 31 Jul 1947, WIS); same location (*Curtis, Greene, and Sauer 1672,* 2 Jul 1954, WIS). Portage Co.: sandy waste area beside town dump, sec. 26, T25N, R10E (*Redmond 441,* 12 Aug 1971, WSO). Flowering late July to late September; fruiting dates probably the same as those for *D. fullonum.*

2. CEPHALARIA Schrad.

Annual or perennial herbs with simple or pinnately divided leaves and flowers in globose heads on long peduncles. Involucral bracts numerous, *imbricate in several rows, not spine-tipped, shorter than the heads. Receptacular bracts more or less sharp-pointed but not spine-tipped,* shorter than the flowers. Involucel 4-angled, *bearing 4 or 8 awn-like appendages* at the apex. Calyx limb shallowly cupulate, denticulate. Flowers similar to those of *Knautia,* the corollas 4-lobed, the *marginal ones sometimes enlarged and ray-like.* Fruit, 4–8-ribbed, prismatic and somewhat fusiform.

Native to the Mediterranean region, Central Asia and South Africa, a few of the 60 species sometimes cultivated.

1. Cephalaria tatarica Schrad. Map 2, circle.

Coarse perennial to 2 m tall, the stems bearing 3–5 heads, retrorsepubescent and leafy below, glabrous and nearly naked above. Cauline leaves deeply pinnately divided, the divisions decurrent, elliptic and coarsely serrate to linear and entire. Heads 2.5–4.5 cm wide, on peduncles 6–30 cm long. *Corollas cream or yellow,* 8–16 mm long, the marginal ones enlarged and ray-like. Involucral bracts ovate, 5–10 mm long, rigid and brown, grading into oblanceolate, abruptly stiff-acuminate receptacular bracts, these 8–12 mm long, about equaling the corolla tube. *Calyx teeth numerous, ca. 25,* 0.5–1 mm long, densely villous. *Achenes 6–9 mm long,* pubescent, *with 8 ribs,* these prolonged as subequal short awns (involucel "teeth") 0.7–1.5 mm long. $2n = 36$.

Native to western Asia, possibly southern Russia, rarely cultivated in flower gardens; collected twice in Wisconsin and perhaps reported here as an escape for the first time from the United States:—Winnebago Co.: N edge of Oshkosh, Algoma Blvd., roadside adjacent plowed field near cemetery, sec. 10, T18N, R16E (*Harriman 3600,* 18 Jul 1968 [fl, fr], WSO, fragment WIS); spreading along road shoulder, same location (*Harriman 9209,* 10 Jul 1973 [fl], WIS, WSO). The collector states that the plant is "as well established as, say, *Sonchus* or *Cirsium.*"

3. KNAUTIA L. BLUEBUTTONS

Annual or perennial herbs with erect stems, pinnatifid leaves and hemispheric to subglobose heads on elongate peduncles. Involucral bracts lanceolate, herbaceous, about equaling the heads. *Receptacle more or less densely hairy, without bracts.* Corollas funnelform to narrowly campanulate, the limbs more or less oblique or bilabiate, 4–5-lobed, those of the marginal flowers often much enlarged. *Involucel strongly compressed, 4-angled, the limb very short, with only a few minute teeth at the summit.* Calyx short, with *8–16 elongate setaceous appendages.* Stigma emarginate.

Native to Eurasia and North Africa, with 40 species.

1. KNAUTIA ARVENSIS (L.) Coult. Map 3.
Bluebuttons, Bluecaps
Scabiosa arvensis L.

Hirsute perennial 4–10 dm tall. Basal leaves oblanceolate, simple or lyrate-pinnatifid. Lower cauline leaves usually only coarsely toothed, the others deeply pinnatifid into 5–15 linear-oblong segments, reduced upward. Peduncles 4–25 cm long. Heads 1.5–4 cm wide, the outer involucral bracts ovate, the inner narrowly lanceolate, 8–16 mm long, herbaceous, about equaling the heads. *Corolla* 8–18 mm long, *lilac-purple. Achenes 4-ribbed, 5–6 mm long, strongly compressed-ellipsoid,* pubescent, the apex truncate, minutely denticulate, crowned by the calyx limb, its 8–16 awns 1.7–3.6 mm long, eventually deciduous. $2n = 20, 40$.

Native throughout Europe except for the extreme North; in Wisconsin a sporadic escape from flower gardens, becoming locally abundant in nearby fields, roadsides and waste places but possibly not persisting. First reported here for the state, although some of the following collections are old:—Ashland Co.: common along roadsides 2 mi. SW of Glidden (*Courtenay s.n.,* 15 Jul 1962, MIL, WIS). Forest Co.: one colony by roadside, with bracken, timothy and dogbane, ½ mi. N of Hwy. 52 on Hwy. W, E side of Richardson Lake (*Kruschke K-65-64,* 15 Jul 1965, MIL). Milwaukee Co.: Whitefish Bay, edge of field (*Sorenson s.n.,* 20 Jun 1912, MIL); Milwaukee, a garden escape, vacant lot on Hopkins St. ½ block S of Villard Ave. (*Fuller F-42-84,* 15 Jul 1942, MIL). Sawyer Co.: colony extending ca. 50 yds. along gravelly roadside through *Picea glauca* plantation, Forest Rd. 162 ca. 1 mi. N of Hwy. 70, sec. 5, T39N, R3W (*Hansen 1943,* 5 Jul 1973, WIS). Fuller's specimen may have sprouted from garden refuse, since *Malva alcea* was collected at the same site (cf. Utech 1970). Flowering June to September.

Many species of *Scabiosa,* especially *S. atropurpurea* L., Sweet Scabious, are popular garden ornamentals that rarely escape from cultivation. The features distinguishing them from *Knautia* include the lanceolate involucral bracts, the 5 calyx setae, the chaffy receptacle, the cupulate involucel limbs, and the terete 8-furrowed fruits. None have been collected in Wisconsin.

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PRELIMINARY REPORTS ON THE FLORA OF WISCONSIN NO. 66. CYPERACEAE II—SEDGE FAMILY II.

The Genus *Cyperus*—The Umbrella Sedges

Brian G. Marcks
University Wisconsin—Madison

Cyperus, a vast genus of upwards of 700 species chiefly distributed in warm temperate and tropical regions of the world, is distinguished from other Cyperaceae by having, in combination, strictly 2-ranked (distichous) scales and terminal umbellate inflorescences or heads. Since the group is technically difficult, examples of inflorescences and their parts have been illustrated in Fig. 1 to aid in the understanding of some of the terminology used in this report. The Wisconsin species flower from midsummer to early fall and occur in dry exposed sandy areas or in various wetland habitats, such as marshes and bogs, swales and low fields, ditches, and lakeshores, riverbanks and streamsides. Several of our species are notable for their widespread distribution. *Cyperus aristatus, C. esculentus* and *C. odoratus* are semi-cosmopolitan in tropical and temperate regions, while *C. Engelmannii* is widely distributed in the New World. *Cyperus strigosus* and *C. esculentus* tend to become weedy in low fields. Phenotypic dwarfing is common and particularly noticeable in depauperate specimens of the taller wetland species, including *C. strigosus, C. erythrorhizos, C. Engelmannii* and *C. odoratus.*

The present paper revises Greene's (1953) preliminary partial treatment of Cyperaceae in Wisconsin, including the genus *Cyperus.* Distribution maps are based on specimens in the herbaria of the University of Wisconsin, Madison (WIS), University of Wisconsin —Milwaukee (UWM), Milwaukee Public Museum (MIL), University of Minnesota (MIN), Field Museum of Natural History (F), Wisconsin State University—Oshkosh (WSO), Wisconsin State University—Stevens Point (WSP), and Northland College, Ashland, Wisconsin (NC). Grateful acknowledgement is due to the curators of the above herbaria for loans of specimens. The results of my master's and doctoral dissertations, population studies of *Cyperus* section LAXIGLUMI in the United States (Marcks, 1967, 1972) have been freely incorporated.

Map dots represent exact locations. The map inset numbers record flowering and fruiting dates as determined from specimens housed at the University of Wisconsin, Madison (WIS). Plants in

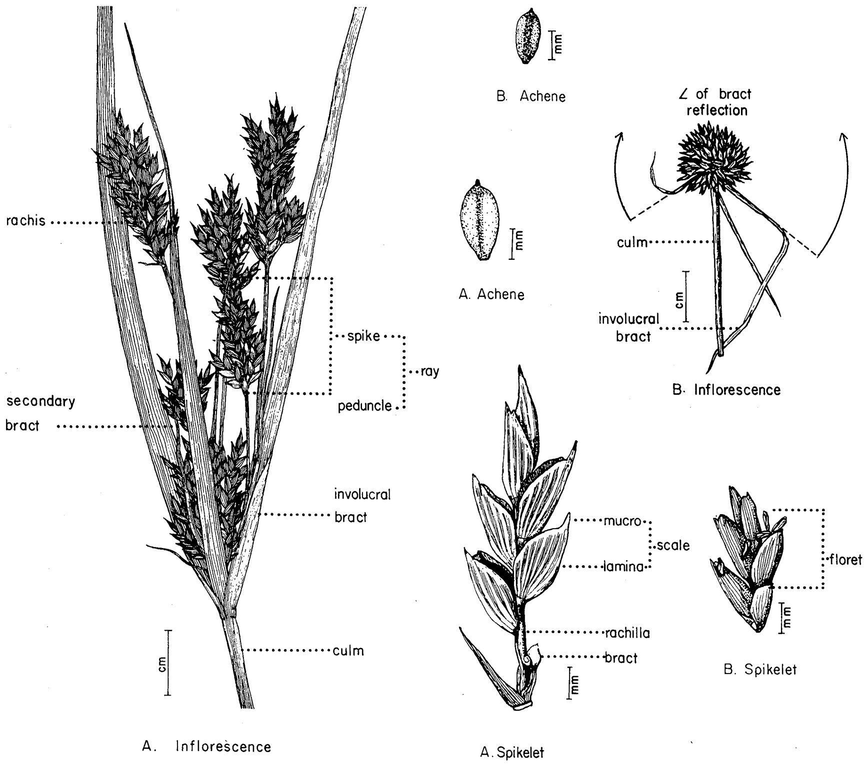


FIGURE 1. Inflorescences, spikelets, and achenes of Wisconsin Umbrella Sedges labelled to illustrate parts and diagnostic characters: A) *Cyperus Schweinitzii;* b) *C. lupulinus* ssp. *macilentus.*

vegetative growth only, in bud, or with dispersed fruit were not included. Triangles in Iowa and Michigan represent county records according to Gilly (1946) and Voss (1972). Most common names are those used by Gilly (1946).

1. CYPERUS L. UMBRELLA SEDGE, FLAT SEDGE, NUT-GRASS, GALINGALE

Mostly low, cespitose annuals or loose-tufted perennials from hard rhizomes or corm-like tubers; culms 3-angled, solid, simple, usually slender and erect, leafy near the base and bearing a leafy involucre at the summit. LEAF blades conduplicate or flat, erect or spreading-arcuate, usually scabrellate on the margins and dorsal midrib, sometimes scaberulous on the ventral surface toward the apex; leaf sheaths glabrous, unpigmented or more commonly tinged reddish-purple, hyaline ventrally, becoming fibrous-shredded. Involucral bracts blade-like, 3-several of unequal lengths, ascending, spreading or reflexed. INFLORESCENCE terminal, an umbel-like aggregation of simple or branched primary spikes (rays) with the central spikes usually sessile or subsessile and the lateral spikes peduncled, or the whole inflorescence contracted into a dense head. Peduncles usually of unequal lengths, ascending or variously divergent, slender and smooth, the lower portion of each enveloped by a tubular sheath (prophyll). SPIKELETS spirally arranged on the spike axis (rachis), subremote to densely congested, divaricate, ascending, radiate or digitate, ovate to oblong-linear, usually laterally compressed, persistent or disarticulating at maturity; rachilla straight or zigzag, often winged on the lateral margins. SCALES strictly 2-ranked, imbricate or subapproximate, persistent or deciduous, green-keeled. Flowers 3-many; stamens 1–3; styles 2-3-cleft. ACHENES lenticular or trigonous, beakless.

KEY TO SPECIES

A. Achenes lenticular; styles 2-cleft; low annuals with strongly flattened lustrous purplish-brown spikelets (Subgenus *Pycreus*, Section SULCATI).

B. Styles exserted about 2 mm, persistent; scales loosely imbricate, the laminae with a depressed membranaceous dull patch surrounded by a broad lustrous purplish-brown margin. ______________________________1. *C. DIANDRUS.*

BB. Styles exserted less than 1 mm, deciduous; scales closely imbricate, the laminae firm, slightly convex, the surface lustrous and purplish-brown throughout (rarely unpigmented). ___________________________2. *C. RIVULARIS.*

AA. Achenes trigonous; styles 3-cleft; habits various (Subgenera *Cyperus, Mariscus, Torulinium*).

C. Scales ending in a long recurved excurrent tip; strongly aromatic dwarf annuals rarely more than 10 cm tall (Section AMBILES). _______________3. *C. ARISTATUS.*

CC. Scales ending bluntly or in a straight or appressed tip; nonaromatic annuals or perennials usually 10–100 cm tall.

D. Spikelets mostly divaricate at nearly right angles (or slightly ascending) from a ± elongate rachis, with only the uppermost and lowest spikelets strongly ascending or deflexed; rachilla winged along lateral margins.

E. Scales 1.2–1.5 mm long, densely aggregated and tinged lustrous copper; achenes ivory or pearly white, 0.8–1.0 mm long (Section FASTIGIATA). __________4. *C. ERYTHRORHIZOS.*

EE. Scales 1.5–4.5 mm long, variously colored; achenes darker, 1.0–2.2 mm long.

F. Spikelets flat or strongly compressed; scales 3.5–4.5 mm long, the laminae uniformly yellow-tinged; achene less than half the scale length (Section STRIGOSI). ____________________ 5. *C. STRIGOSUS.*

FF. Spikelets not strongly flattened; scales 1.5–3.0 mm long, the laminae golden-brown to reddish-brown; achene over half the scale length, or female sterile.

G. Perennials bearing stolons with prominent membranaceous scales, each terminated by a hard tuber; rachilla not breaking into segments (Section ESCULENTI). ______________________________ 6. *C. ESCULENTUS.*

GG. Annuals from fibrous roots; rachilla breaking into short segments at maturity (Section FERACES).

H. Apex of scales overlapping superjacent scales. ________________________ 7. *C. ODORATUS.*

HH. Apex of scales not overlapping superjacent scales, giving the spikelet a zigzag appearance. _______ 8. *C. ENGELMANNII.*

DD. Spikelets radiate to subdigitate from a short rachis or ascending from an elongate rachis; rachilla essentially wingless (Section LAXIGLUMI).

I. Achenes about twice as long as wide, the faces flat or only slightly concave.

J. Inflorescence a single, sessile, dense hemispherical to nearly spherical head (rarely with 1–2 additional pedunculate spikes); involucral bracts commonly deflexed; culms smooth. ______________ 9. *C. LUPULINUS.*[1]

JJ. Inflorescence an open umbel with 1–8 pedunculate spikes; involucral bracts ascending; culms markedly scabrous on angles near the apex. ____________ 10. *C. SCHWEINITZII.*[1]

[1] Hybrids between species 9 and 10 are common in Wisconsin (cf. Hybridization in the *C. lupulinus-C. Schweinitzii* complex, p. 276).

II. Achenes much less than twice as long as wide, the faces markedly concave. -- 11. *C. HOUGHTONII.*[1]

1. CYPERUS DIANDRUS Torr. Map 1.
Low Cyperus

Rather soft, tufted or solitary low annuals 3–24 (–35) cm tall. Culms rather weak, 2–26 cm long, smooth, the tufted forms sometimes with secondary cushion-like inflorescences directly from the base. Blades 1–3 mm wide, with membranaceous loose-fitting sheaths enveloping the lower ⅓ of the culm; involucral bracts blade-like, mostly 3, divergent. Inflorescence a subglobose cluster of loose spikes, usually with 1–5 pedunculate rays up to 6 cm long in addition. Spikelets subdigitate to pinnate from a rachis to 12 mm long, lance-oblong, flat, 5-40-flowered, 4–26 mm long; rachilla persistent. Scales loosely imbricate, the achenes usually visible under the margins, 2.0–2.7 mm long, deciduous, nerved only on the green keel, the tip appressed; *laminae with a dull depressed scarious patch banded by a wide lustrous purplish-brown margin.* Stamens 2. Style 2-cleft nearly to the base, *long-exserted (to ca 2 mm) beyond the scale, persistent. Achene lenticular,* ellipsoid to narrowly ovoid, ca 1.2 mm long, whitish to reddish-brown.

A wetland species ranging from North Dakota and Missouri east to Quebec and Virginia, infrequent in Wisconsin on wet sandy to muddy shores and banks of rivers, streams, and lakes, sometimes in peaty soil of sedge mats, becoming rare northward; often confused with *C. rivularis,* but distinguished by its long-exserted, persistent styles and the depressed scarious patch on each scale lamina. Flowering from July to October; fruiting from late July to late October.

2. CYPERUS RIVULARIS Kunth Map 2.
Shining or Brook Cyperus

Mostly low tufted annuals 3–25 (–32) cm tall, erect or spreading. Culms firm, smooth, 2–24 cm long, the plants often with secondary cushion-like inflorescences directly from the base. Blades 0.5–2.0 mm wide, with rather tight-fitting sheaths enveloping less than ⅓ of the culm; involucral bracts blade-like, 1–3, divergent. Inflorescence a terminal umbel composed of a subglobose cluster of loose spikes, with an additional 1–5 rays up to 6 cm long. Spikelets subdigitate to pinnate from a rachis to 1 cm long, lance-oblong, flat, 6–38-flowered, 4–23 mm long; rachilla persistent. Scales closely imbricate, completely covering the achenes, 1.8–2.2

mm long, nerved only on the green keel, the tip appressed; *laminae firm, slightly convex, lustrous purplish-brown* (rarely unpigmented). Stamens 2. Style 2-cleft to about the middle, *exserted less than 1 mm, deciduous. Achene lenticular,* ellipsoid to narrowly obovoid, whitish to reddish-brown, ca 1.2 mm long.

A common wetland species of wide distribution in temperate North America, in Wisconsin in wet sand and mud of shores and banks of lakes, rivers and streams, and in low fields, ditches and marshes; easily confused with *C. diandrus,* but distinguished by firm, closely imbricate scales with lustrous purplish-brown laminae and the absence of long-exserted, persistent styles. Flowering from early July to early October; fruiting from August to mid-October.

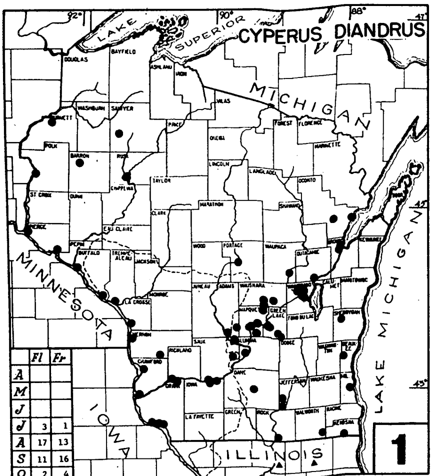
3. CYPERUS ARISTATUS Rottb. Map 3.
Awned Cyperus
C. inflexus Muhl.
C. aristatus var. *inflexus* (Muhl.) Kükenth.

Mostly tufted, soft-based low delicate annuals 2–18 cm high, from red fibrous roots, *strongly aromatic,* with the fragrance of *Ulmus rubra* or *Gnaphalium obtusifolium.* Culms slender, flaccid, smooth, sharply wing-angled. Blades 1–3 mm wide, from deep purplish-red sheaths; involucral bracts blade-like, mostly 3, divergent. Inflorescence a dense hemispherical to subglobose head, usually with 1–3 additional rays. Spikelets subdigitate from a short rachis, somewhat flattened, 3-23-flowered, 2–9 mm long; rachilla persistent. Scales 1.5–2.5 mm long, the keel green, *narrowed to a long recurved excurrent tip;* laminae 3-5-nerved, pale yellow to rich copper. Stamen 1. Style 3-cleft. *Achene trigonous,* slenderly obovoid, ca 0.8 mm long, pale brown.

Semi-cosmopolitan species of north temperate and tropical regions, occurring in the western two-thirds of Wisconsin in wet sand and mud of river bars and banks, lakeshores, moist depressions and temporary pools. Flowering from July to October; fruiting from mid-July to mid-October (n = ca 24, 28, 32; Murdy, 1968).

4. CYPERUS ERYTHRORHIZOS Muhl. Map 4.
Red-rooted Cyperus

Annuals from fibrous, *caked blood-red roots.* Plants erect and solitary, 1–4 (–8) dm tall, or spreading from loose tufts, sometimes dwarfed and only to 2 cm tall. Culms firm, smooth, coarsely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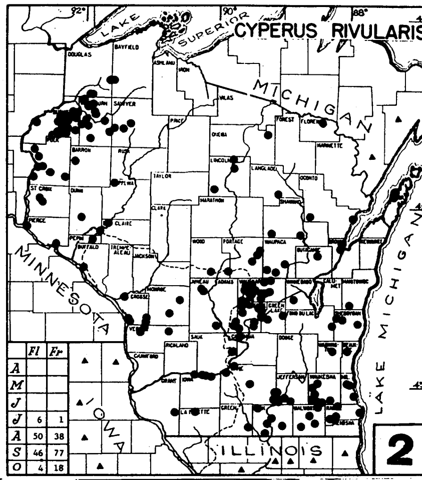
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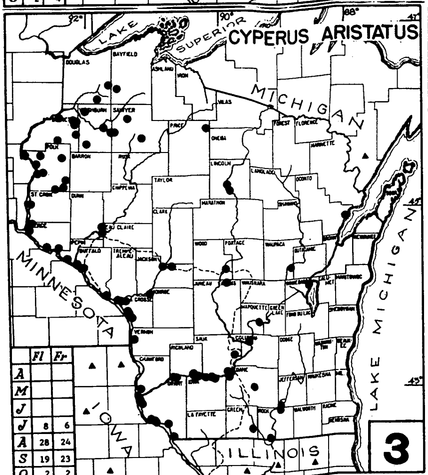
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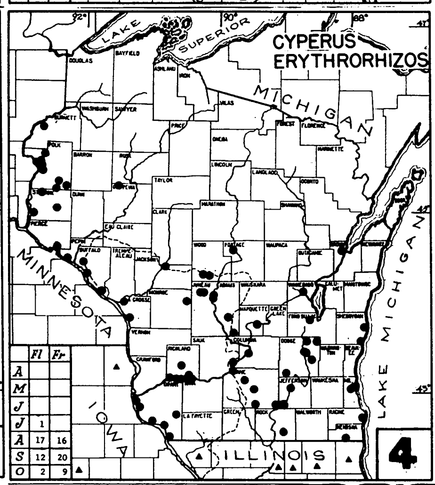
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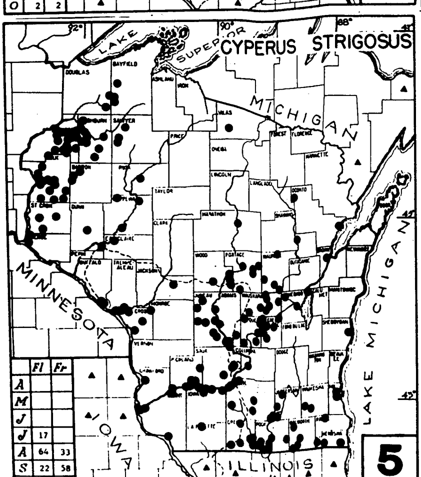
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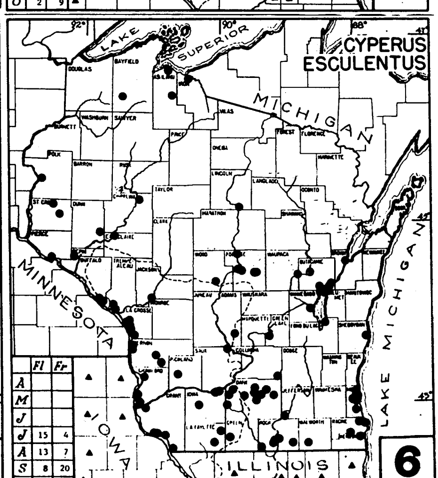
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3-angled. Blades soft, scabrous apically, pale beneath, 2–6 mm wide; involucral bracts blade-like, 3–9, spreading. Inflorescence a compound umbel, rarely simple or condensed, with a cluster of subsessile spikes and in addition 1–7 unequal divergent pedunculate rays 1–10 cm long. Spikelets crowded, mostly radiating horizontally from an elongate rachis 5–30 mm long, slenderly oblong, 5-30-flowered, 3–20 mm long, ca 1 mm wide; rachilla persistent, bearing deciduous chaffy wings. Scales small and delicate, 1.2–1.5 mm long, densely aggregated; keel broad and green; *laminae lustrous copper to rich reddish-brown.* Achene plano-convex, short ellipsoid to ovoid, ca 0.8 mm long, *lustrous ivory to pearly white.*

Widely distributed wetland species of temperate North America, in Wisconsin common in the southwest, absent in the northeast, on wet sandy or muddy shores of lakes, rivers and streams and in marshes and wet ditches. Flowering from mid-July to October; fruiting from August to early November.

5. CYPERUS STRIGOSUS L. Map 5.
Straw-colored Cyperus

Erect perennials 1–6 (–10) dm tall, the base becoming a hard corm-like rhizome. Culms firm, smooth, acutely 3-angled. Blades 2–6 mm wide, flat, apically scabrous; involucral bracts blade-like, 3–8, divergent, often greatly exceeding the umbel. Inflorescence a simple or compound umbel with a cluster of subsessile spikes and 1–12 unequal, obliquely ascending pedunculate rays to 12 cm long. Spikelets usually crowded, mostly radiating horizontally from a ± elongate rachis 4–28 mm long, linear-lanceolate, *strongly flattened,* 4-14-flowered, 5–18 mm long, ca 2 mm wide; rachilla deciduous, winged. *Scales oblong-lanceolate, 3.5–4.5 mm long, loosely imbricate,* the keel green; laminae uniformly tinged yellow, the margins spreading. *Achene less than half the length of the scale,* trigonous and slender, 1.6–2.2 mm × 0.5–0.6 mm, purplish-brown.

A widespread and variable North American species, very common in all but northeast Wisconsin, in wet sand and mud of meadows, swales and sloughs, temporary pools and ditches, and shores and banks of lakes, rivers and streams; sometimes weedy in low fields. Flowering from July to October; fruiting from August to mid-October.

6. CYPERUS ESCULENTUS L. Map 6.
Yellow Nut-grass, Chufa

Robust erect perennials from thickened bases, *bearing soft stolons with prominent scales, each stolon terminated by a hard* *tuber*. Culms 2–9 dm high, acutely 3-angled, smooth and subcoriaceous at base, soft and scabrous at the apex; involucral bracts blade-like, 2–9, exceeding the umbel, spreading. Inflorescence an open and often compound umbel of several subsessile spikes, with several additional ascending pedunculate rays 1–10 dm long. Spikelets mostly 4-ranked along an elongate rachis 1–3 cm long, loosely aggregated and spreading nearly horizontally, *barely flattened,* 5–25 mm long, 5-28-flowered; *rachilla persistent,* narrowly winged. *Scales overlapping,* 2–3 mm long, yellowish-brown to golden brown. *Stamens 3, 1.2–1.5 mm long.* Achene trigonous, ellipsoid to obovoid, rounded at the summit, 1.2–1.6 mm long (sometimes female sterile), *lustrous tan to golden brown.*

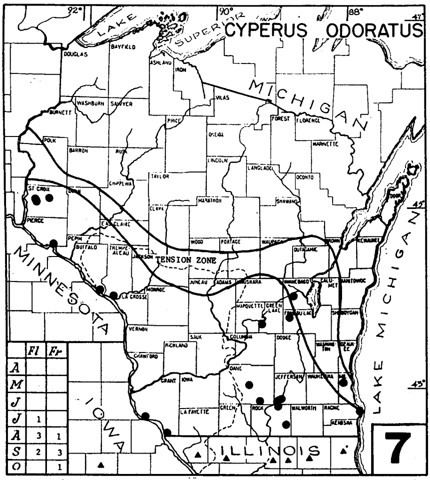
A widely distributed pantropical and warm temperate weed, sparingly throughout Wisconsin in wet sand or mud of lakeshores and riverbanks, and as a weed in low fields and roadsides. Flowering from July to October; fruiting from mid-July to mid-October (2n = 108; Hicks, 1929; Darlington and Wylie, 1955).

7. CYPERUS ODORATUS L. Map 7.
Coarse Cyperus

C. ferruginescens Böeckl.
C. speciosus var. *squarrosus* Britt.
C. speciosus var. ferruginescens (Böeckl.) Britt.
C. ferax ssp. speciosus (Britt.) Kükenth.
C. odoratus var. *squarrosus* (Britt.) Gilly

Fibrous-rooted annuals 2–60 cm tall, erect or dwarfed, spreading from loose tufts. Culms several, smooth, firm, acutely 3-angled. Blades flat, apically scabrous; involucral bracts blade-like, 3–6, spreading, sometimes greatly exceeding the umbel. Inflorescence a compound umbel (or condensed into a loose head-like cluster), with several loose subsessile spikes and up to 7 unequal divergent pedunculate rays 1–6 cm long. Spikelets closely aggregated along a ± elongate rachis 5–20 mm long, mostly spreading horizontally or slightly ascending, slender and subterete, 4-20-flowered, 4–26 mm long; *rachilla breaking into 1-fruited sections at maturity,* winged. *Scale with apex overlapping superjacent scale,* 1.5–2.0 mm long, the keel green; laminae reddish-brown. *Stamens 3, 0.3–0.5 mm long.* Achene trigonous-oblongoid, 1–1.5 mm long, *ferruginous to golden brown.*

The entity from the interior of temperate North America, formerly treated as *C. ferruginescens* Böeckeler but inseparable from the semi-cosmopolitan tropical and subtropical *C. odoratus* (O'Neill, 1942), is of infrequent occurrence in Wisconsin south of


CYPERUS ODORATUS
LAKE SUPERIOR
MICHIGAN
TENSION ZONE
MINNESOTA
IOWA
ILLINOIS
LAKE MICHIGAN
Fl Fr
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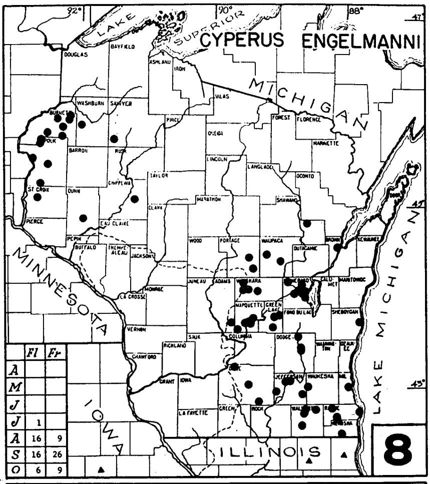
J 1
A 3 1
S 2 3
O 1
7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MICHIGAN
MINNESOTA
IOWA
ILLINOIS
LAKE MICHIGAN
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A
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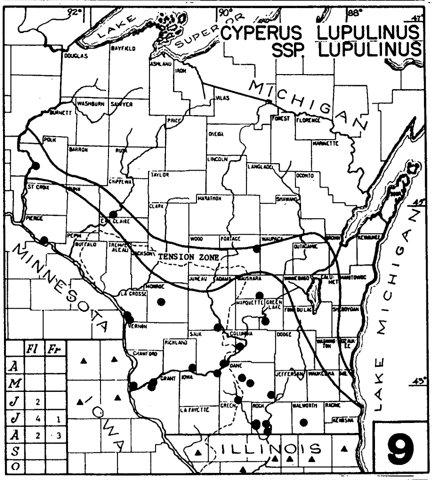
J 1
A 16 9
S 16 26
O 6 9
8


CYPERUS LUPULINUS
SSP. LUPULINUS
LAKE SUPERIOR
MICHIGAN
TENSION ZONE
MINNESOTA
IOWA
ILLINOIS
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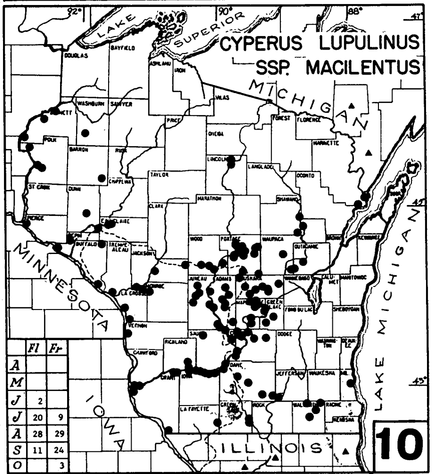
J 2
J 4 1
A 2 3
S
O
9


CYPERUS LUPULINUS
SSP. MACILENTUS
LAKE SUPERIOR
MICHIGAN
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S 11 24
O 3
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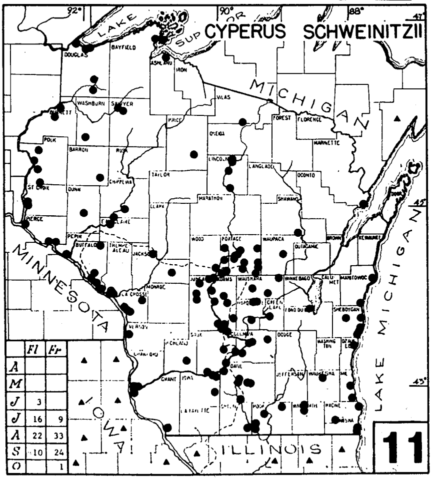
CYPERUS SCHWEINITZII
LAKE SUP
MICHIGAN
MINNESOTA
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ILLINOIS
LAKE MICHIGAN
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A
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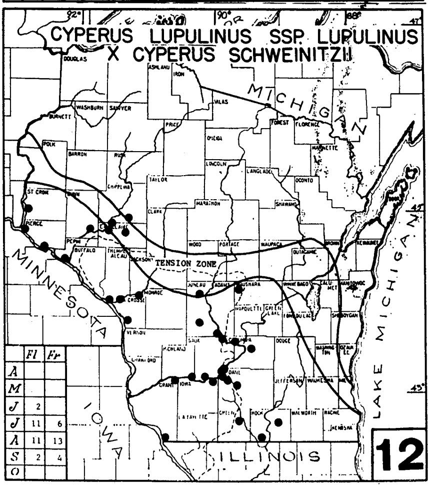
J 16 9
A 22 33
S 10 24
O 1
11


CYPERUS LUPULINUS SSP. LUPULINUS
X CYPERUS SCHWEINITZII
MICHIGAN
TENSION ZONE
MINNESOTA
IOWA
ILLINOIS
LAKE MICHIGAN
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J 11 6
A 11 13
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the Tension Zone, in wet sand and mud of riverbanks, flats, sloughs, lakeshores and marshes. The Wisconsin plants appear to belong to var. *squarrosus,* which according to Gilly (1946) "is essentially restricted to the Mississippi Valley, the Great Lakes area, and the Western Gulf Coastal Plain. . . [as an] . . . interior and western phase of the species, with the thinner, dull-brown to greenish scales. . ." Often confused with *C. Engelmannii* and *C. esculentus,* it is distinguished from the former by its subapproximate, overlapping scales and from the latter by its lack of scaly stolons and tubers and its much shorter stamens. Flowering from July to September; fruiting from August to October.

8. CYPERUS ENGELMANNII Steud. Map 8.
Engelmann's Cyperus

Fibrous-rooted annuals 2–60 cm tall, erect or dwarfed and spreading from loose tufts. Culms smooth and firm, sharply 3-angled. Blades flat, scaberulous apically, the sheaths light reddish-purple; involucral bracts blade-like, 3–8, spreading, often greatly exceeding the umbel. Inflorescence a compound umbel (or condensed into a loose head-like cluster) with several subsessile spikes and up to 7 unequal divergent pedunculate rays 1–6 cm long in addition. Spikelets closely aggregated along a ± elongate rachis 4–15 mm long, mostly spreading horizontally or slightly ascending, slenderly subterete, 6-18-flowered, 8–24 mm long; *rachilla splitting into 1-fruited sections at maturity,* winged. Scales thin, *remote and not overlapping the superjacent scale (giving the spikelet a zigzag appearance),* 1.5–3.0 mm long; keel green; laminae golden brown to reddish-brown. Achene trigonous, linear-oblongoid, ca 1.5 mm long, brownish.

Widely distributed wetland species of tropical and warm temperate regions of the New World, in Wisconsin mostly in the northwest and southeast, in wet sand or mud of lakeshores, ditches and marshes. Flowering from late July to early October; fruiting from early August to mid-October.

9. CYPERUS **LUPULINUS** (Spreng.) Marcks, comb. nov.
Slender stemmed Cyperus

Scirpus lupulinus Spreng. Mant. 1:30. 1807. TYPE: Muhlenberg from eastern Pennsylvania, in the Berlin Herbarium (B), photograph (WIS!). The type sheet is a mixed collection; the plant on the left is taken as the lectotype, since the plant on the right appears to be *Cyperus lupulinus* ssp. *macilentus.*
Cyperus filiculmis of many authors, not of Vahl, 1806.

Erect perennials 8–40 cm high, mostly in loose tufts from hard subglobose corm-like rhizomes. *Culms very slender,* rigid and erect, 3-angled, 0.4–1.2 mm thick near the apex. Blades pale green, narrow, 1–3.5 mm wide, mostly conduplicate, scabrous-margined; involucral bracts 3–4, blade-like, mostly deflexed. *Inflorescence a single, sessile, dense hemispherical to nearly spherical head,* 8–25 mm in diameter, rarely with 1–2 additional rays. *Spikelets radiate and densely congested, from 3–4 very short axes,* 3-22-flowered, 3–22 mm long, 2.5–4.0 mm wide; rachilla late-deciduous, essentially wingless. Scales oblong, 1.8–3.8 mm long, readily deciduous; keel green, short-mucronate; laminae unpigmented or tinged reddish-brown. Achene trigonous, narrowly ovoid to oblongoid, 1.4–2.2 mm × 0.6–1.1 mm, dark brown or black.

Cyperus lupulinus is usually included in *C. filiculmis* Vahl, an endemic of the southern Atlantic and Gulf Coastal Plains of the United States, but the two are distinguishable by several morphological characters. The former has green rather than yellow scales, wider achenes, and longer scale mucros. Moreover, biosystematic studies (Marcks, 1972) have shown *C. lupulinus* to be essentially allopatric in more northern and western regions and to have a different chromosome number and phenolic profile pattern. These data strongly support recognition of *C. lupulinus* as a species separate from *C. filiculmis.*

The first legitimate epithet for this taxon is *Scirpus lupulinus* Sprengel, dating from 1807. It is based on *Muhlenberg 203* from Pennsylvania (now in the Willdenow Herbarium in Berlin, number 1221). A photograph of this sheet (WIS!) shows it to be annotated in Sprengel's hand as "Scirpus lupulinus n. s." The sheet bears two specimens, the left-hand one clearly referable to the typical form of the species in the length of its scales (2.8–3.0 mm long), spreading scale margins and several-flowered spikelets, the right-hand one probably referable to ssp. *macilentus* (described below) on the basis of its 3-4-flowered spikelets and slightly shorter scales (ca 2.5 mm long). Because the identification of the latter specimen is questionable from the photograph, the specimen on the left is taken as the lectotype for Sprengel's name.

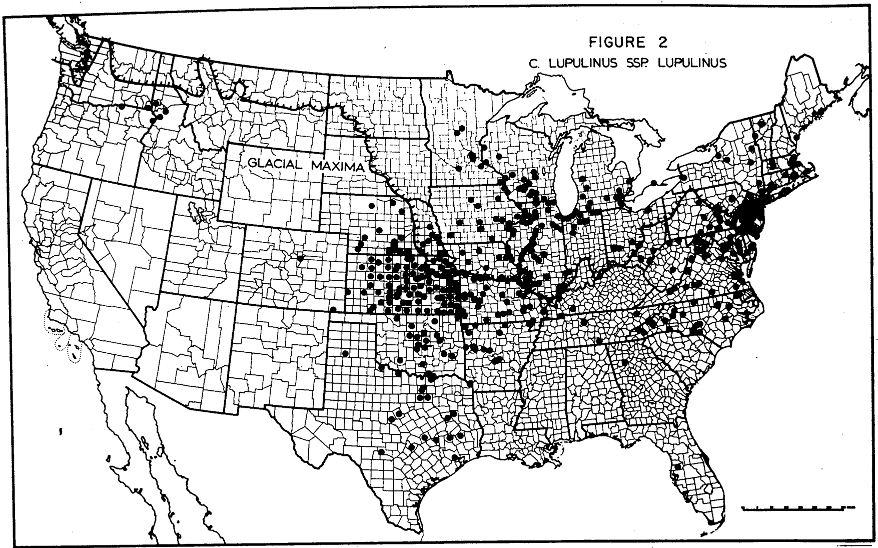
KEY TO SUBSPECIES

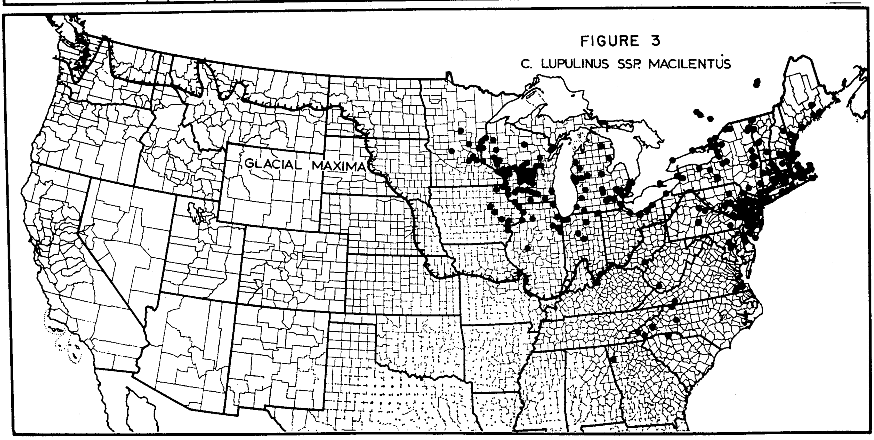
A. Scales 2.5–3.5 mm long, fitting loosely over the achene, the margins spreading; spikelets 6-22-flowered.
9a. *C. LUPULINUS* SSP. *LUPULINUS.*

AA. Scales 1.8–2.5 mm long, fitting firmly over the achene, the margins tightly clasping; spikelets 3–5 (–7) flowered.
9b. *C. LUPULINUS* SSP. *MACILENTUS.*

9a. CYPERUS LUPULINUS (Spreng.) Marcks ssp. LUPULINUS Map 9, Figs. 2 and 5, Table 1.

Mariscus glomeratus Bart. Prod. Fl. Phil. 18. 1815, *fide* Horvat, 1941 (under C. *filiculmis, sensu lato*).
Scirpus cyperiformis Muhl. Descr. 41. 1817. TYPE: Baltimore, Maryland, *Muhlenberg 143* sheet 2 in folder 46 (PH!).
Mariscus cyperiformis (Muhl.) Torr. Cat. Pl. N. Y. 14. 1819.
? *Cyperus annuus* Spreng. et Link, Jahr. 2:83. 1820, *fide* Kükenth., 1936.





FIGURES 2 AND 3. Distribution maps of *Cyperus lupulinus* ssp. *lupulinus* and *C. lupulinus* ssp. *macilentus*.

Cyperus etesios Schult. Mant. 2:114. 1824, *fide* Kükenth., 1936. *Cyperus Bushii* Britt. Man. Fl. N. U. S. 1044. 1901. Arkansas, Sept. 28, 1894, *Bush 619*. HOLOTYPE: (NY); ISOTYPE (MO!). *Cyperus Houghtonii* var. *Bushii* (Britt.) Kükenth. in Engler, Pflanzenr. 20:470. 1936.

Widespread in the eastern United States on dry exposed sands, gravels and rocky areas of prairies and oak openings, with geographical dispersal centers in the Ozarks and Appalachians, in Wisconsin rather rare, chiefly south of the Tension Zone on sandstone and granite outcrops, gravelly areas and sand prairies (Fig. 2).

More southwestern in distribution than ssp. *macilentus,* with which it intergrades where sympatric in glaciated territory from the upper Midwest eastward to the Atlantic Coastal Plain. Population studies (Marcks, 1972) have shown it to hybridize extensively in the Great Plains and lower Great Lakes region (including southern Wisconsin) with *Cyperus Schweinitzii* (cf. p. 276).

TABLE 1. MORPHOLOGICAL COMPARISON OF *CYPERUS LUPULINUS* SSP. *LUPULINUS, C. LUPULINUS* SSP. *MACILENTUS,* AND *C. SCHWEINITZII.*

Character	ssp. lupulinus	ssp. macilentus	Schweinitzii
Culm width (mm)	0.5-1.2	0.4-1.0	1.0-2.0
Culm angle sharpness	obtusely 3-angled	obtusely 3-angled	acutely 3-angled
Culm scabrosity	smooth	smooth	scabrous
Leaf width (mm)	1.2-3.8	1.0-2.8	2.5-8.0
Bract divergence	reflexed downward	reflexed downward	strongly ascending
Spike density	dense	dense	loose
Ray number	0, rarely 1-4	0, rarely 1-3	3-8
Rachis length (mm)	2.0-5.0	1.0-3.5	4.0-15.0
Spikelet divergence	radiate	radiate	appressed-ascending
Spikelet width (mm)	2.9-4.2	2.4-3.2	3.5-4.5
Flowers/spikelet	5-18	3-5 (7)	4-18
Scale remoteness	1.2-1.8	1.2-1.8	1.6-2.0
Scale margin involution	loosely clasping to spreading	clasping	clasping-involute
Scale length (mm)	2.5-3.8	1.8-2.5	2.4-3.2
Mucro length (mm)	0.15-0.30	0.1-0.2	0.5-1.0
Anther length (mm)	0.3-0.5	0.3-0.5	0.6-1.0
Achene length (mm)	1.7-2.2	1.5-1.8	2.2-2.8
Achene width (mm)	0.8-1.2	0.6-0.8	1.1-1.4

A comparison of morphological characters of the latter taxon is made with those of *C. lupulinus* ssp. *lupulinus* and *C. lupulinus* ssp. *macilentus* in Table 1. Flowering from late June to October; fruiting from mid-July to mid-October (n = ca 83; Marcks, 1972).

9b. CYPERUS LUPULINUS (Spreng.) Marcks ssp. **MACILENTUS** (Fern.) Marcks, stat. nov. Map 10, Figs. 1B, 3 and 6, Table 1.

Cyperus filiculmis Vahl var. *macilentus* Fern., Rhodora 8:128. 1906. TYPE: Valley of the main Penobscot River, in sandy soil, Penobscot Co., Maine, *Fernald 243*. HOLOTYPE: Gray Herbarium (GH !); ISOTYPES (B! C! LCU! PH! MO! US! WIS!). *Cyperus macilentus* (Fern.) Bickn., Bull. Torr. Bot. Cl. 35:478. 1908.

Dry exposed sands, from the southern Appalachians to the Atlantic Coastal Plain of Virginia, northwestward in glaciated territory to Iowa and Minnesota (Fig. 3), in Wisconsin in sandy soil of rock outcrops, roadcuts, abandoned fields, young pine plantations and of glacial lake beds and outwash plains.

Morphologically a highly reduced northeastern segregate of the above typical subspecies largely confined to glaciated eastern North America with an apparent center of dispersal in the northern Appalachians. Previously always included in synonomy with or as a variety of *C. filiculmis*, an endemic of the southern Atlantic and Gulf Coastal Plains, but specifically distinct on the basis of fewer flowered spikelets, unpigmented scale laminae and shorter achenes. Flowering July to October; fruiting mid-July to mid-October (n = ca 83; Marcks, 1972).

10. CYPERUS SCHWEINITZII Torr. Schweinitz's Cyperus Map 11. Figs. 1A, 4, 5 and 6, Table 1.

Erect loose-tufted perennials 2.5–9 dm high, from vertical, hard, corm-like rhizomes 0.8–3 cm long, these branched horizontally and bearing secondary shoots. Culms rigid, sharply 3-angled, *scabrous on the angles near the apex,* 1–2 mm thick. Blades 2–8 mm wide, pale green, scabrous-margined; involucral bracts blade-like, *strongly ascending*. Inflorescence an open umbel, with a cluster of subsessile spikes and in addition 3–8 unequal, strongly ascending pedunculate rays 1–12 cm long. Spikelets loosely disposed from an elongate rachis 5–11 mm long, ascending, ovate to oblong-lanceolate, 3-12-flowered, 5–15 mm long, 3–4 mm wide; rachilla very late-deciduous, essentially wingless. Scales firm, ovate, fitting tightly over the achene, their keels green, each ending in a well

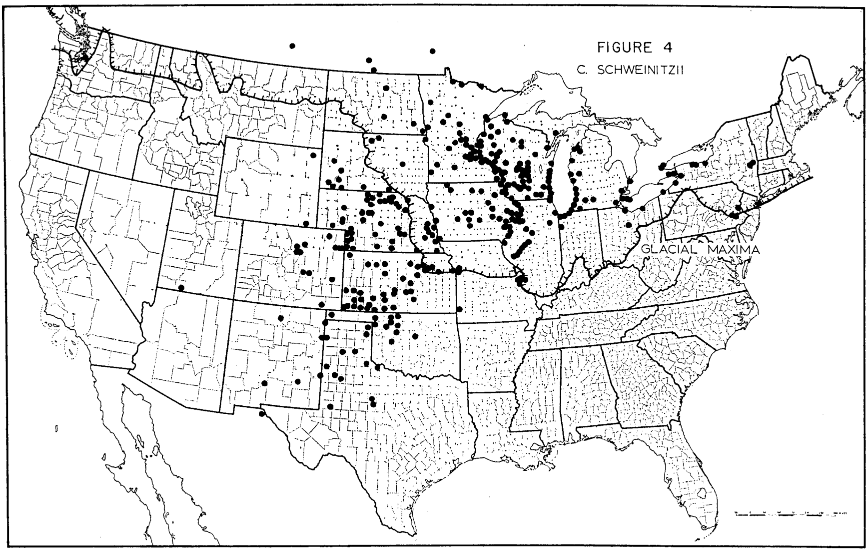


FIGURE 4. Distribution map of *Cyperus Schweinitzii.*

developed mucro 0.5–1.0 mm long. Achene trigonous-ellipsoid, 2.2–2.6 mm × 1.2–1.4 mm, brown or black.

A southern Great Plains element of sand hills and sand prairies (Fig. 4), in Wisconsin rather common in dry exposed sands of glacial outwash plains, river floodplains, dunes of Lake Michigan, sandstone outcrops, and disturbed sands of roadcuts, sandblows and pine plantations. Hybridizes extensively in Wisconsin with *C. lupulinus* ssp. *lupulinus* and ssp. *macilentus* (cf. following section). Flowering from mid-June to late September; fruiting from July to early October (n = ca 83; Marcks, 1972).

HYBRIDIZATION IN *CYPERUS* SECTION *LAXIGLUMI* IN WISCONSIN: THE *C. LUPULINUS-C. SCHWEINITZII* COMPLEX

Cyperus lupulinus ssp. *lupulinus, C. lupulinus* ssp. *macilentus* and *C. Schweinitzii,* all members of the taxonomically difficult section LAXIGLUMI, are often sympatric in dry exposed sands of prairie blowouts, roadcuts, abandoned fields and young pine plantations, sandstone outcrops and lake dunes in glaciated Eastern North America. Wherever they occur together, they hybridize extensively (Marcks, 1967, 1972; Marcks and Iltis, 1967). It is a fact of greatest phytogeographic significance that many taxonomically perplexing groups in glaciated eastern North America, such as the

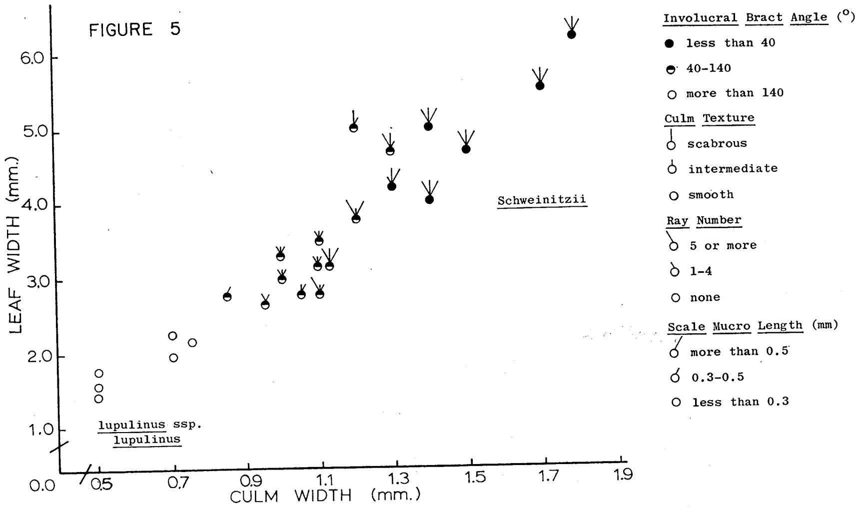


FIGURE 5. Scatter diagram of Wisconsin (WIS) and Illinois State Natural History Survey (ILLS) herbarium specimens of the *Cyperus lupulinus-C. Schweinitzii* complex collected in Mason and Tazewell Counties, Illinois (adjacent counties in central Illinois), clearly showing intermediates between *C. lupulinus* ssp. *lupulinus* (lower left) and *C. Schweinitzii* (upper right).

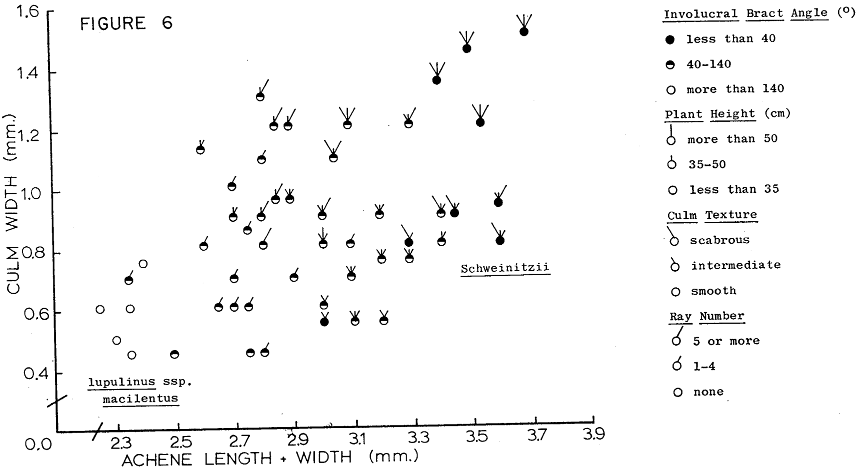


FIGURE 6. Scatter diagram of mass collection (*Marcks & Marcks 358*, collected 2 mi. E of Big Flats, Juneau Co., Wis.) clearly showing intermediates between *Cyperus lupulinus* ssp. *macilentus* (lower left, hollow circles and one or no whiskers) and *C. Schweinitzii* (upper right, solid circles and three whiskers).

C. lupulinus-C. Schweinitzii complex, owe their complexity to postglacial hybridization of closely related species, often vicariads, which evidently met after their long Pleistocene separation in sometimes far removed "refugia" or "survivia" located south of the glacial maxima (Hultén, 1937; Iltis, 1965, 1966, unpublished). Notable examples which show this phytogeographic pattern and which form often spectacular hybrid swarms in glaciated territories include *Actaea pachypoda* and *A. rubra* (Kane, 1966; Iltis, 1966), *Juniperus horizontalis* and *J. virginiana* (Fassett, 1945), *Acer nigrum* and *A. saccharum* (Desmarais, 1952), *Helianthus giganteus* and *H. grosseserratus* (Long, 1961) and *Gentianopsis crinita* ssp. *crinita* and *G. crinita* ssp. *procera* (Iltis, 1965).

Judging from the extraglacial distributions of these LAXIGLUMI taxa, *C. lupulinus* ssp. *lupulinus* survived glaciation in the Ozarks (and perhaps the Appalachians; Fig. 2), *C. lupulinus* ssp. *macilentus* on the Atlantic Coastal Plain and in the Appalachians (Fig. 3), and *C. Schweinitzii* in the southern Great Plains (Fig. 4). Postglacial migrations into once glaciated eastern North America resulted in regions where two or three of these taxa are sympatric. There, subsequent hybridization with backcrossing apparently accounts for the complex intergrading variation patterns often displayed by local populations of this complex (Figs. 5 and 6).

Postglacial hybridization of *C. lupulinus* ssp. *lupulinus* and *C. Schweinitzii* seems merely to have resulted in a blurring of species lines and a great increase in population variability in regions of sympatry. There may also be some introgression northward in glaciated territory, since northern plants of either taxon commonly vary slightly in the direction of the other taxon. In contrast, hybridization between *C. lupulinus* ssp. *macilentus* and *C. Schweinitzii,* aside from resulting in numerous highly variable hybrid swarms, especially in areas of recent human disturbance, appears to have resulted in the origin of a new species, *C. Houghtonii*, within the last 10,000 years in naturally disturbed "Jack Pine" *(Pinus Banksiana)* barrens of the upper Great Lakes region, a hypothesis discussed more fully below.

Key to Hybrid Forms

A. Rachis 5–10 mm long; scales 3.0–3.5 mm long, fitting loosely over the achene, the margins spreading. _11a. *C. LUPULINUS* SSP. *LUPULINUS* × *C. SCHWEINITZII.*

AA. Rachis 2–5 mm long; scales 2.2–3.2 mm long, fitting firmly over the achene, the margins clasping the achene. ______________________11b. *C. LUPULINUS* SSP. *MACILENTUS* × *C. SCHWEINITZII.*

11a. CYPERUS LUPULINUS (Spreng.) Marcks ssp. LUPULINUS × C. SCHWEINITZII Torr. Map 12, Fig. 7.

Cyperus × mesochorus Geise, Amer. Midl. Nat. 15:249. 1934.
Cyperus Houghtonii var. *uberior* Kükenth. in Engler, Pflanzenr. 20:469. 1936.

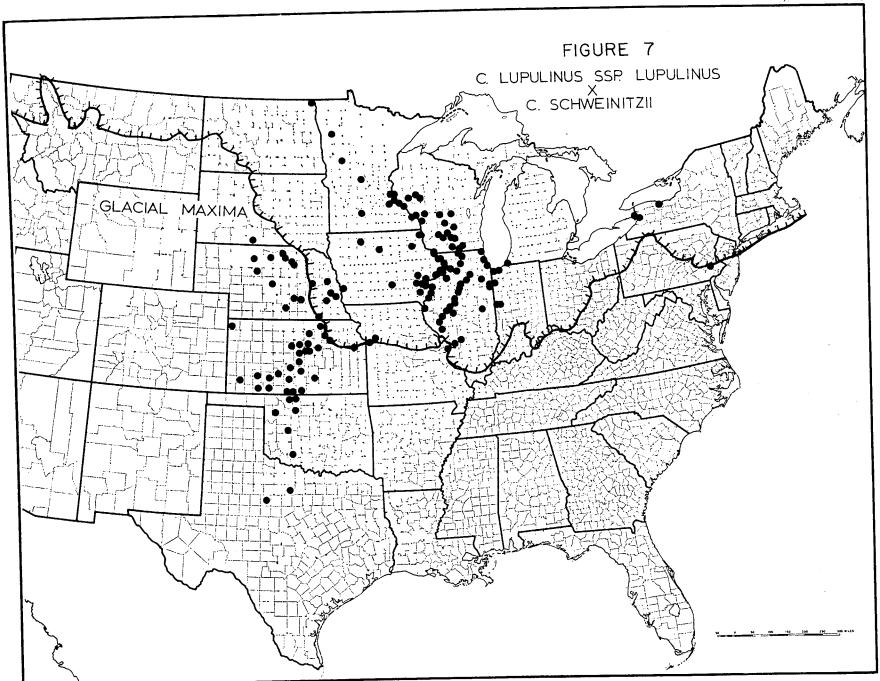
Usually similar to *C. Schweinitzii,* but with fewer rays, more divergent involucral bracts and rays and only slightly scabrous culms; sometimes with reduced seed set. These variable hybrids occur in overgrazed or disturbed sands of sand prairies and sand hills from the southern Great Plains northeastward in glaciated territory to similar habitats in the lower Great Lakes region and eastward more locally to eastern Pennsylvania (Fig. 7), in Wisconsin confined to disturbed sand prairies and outcrops south of the Tension Zone. Hybrid scatter diagrams of local or regional populations of this complex often show a great wealth of variously intermediate plants, suggesting crossing and backcrossing (Fig. 5). Flowering and fruiting synchronously with the parents.

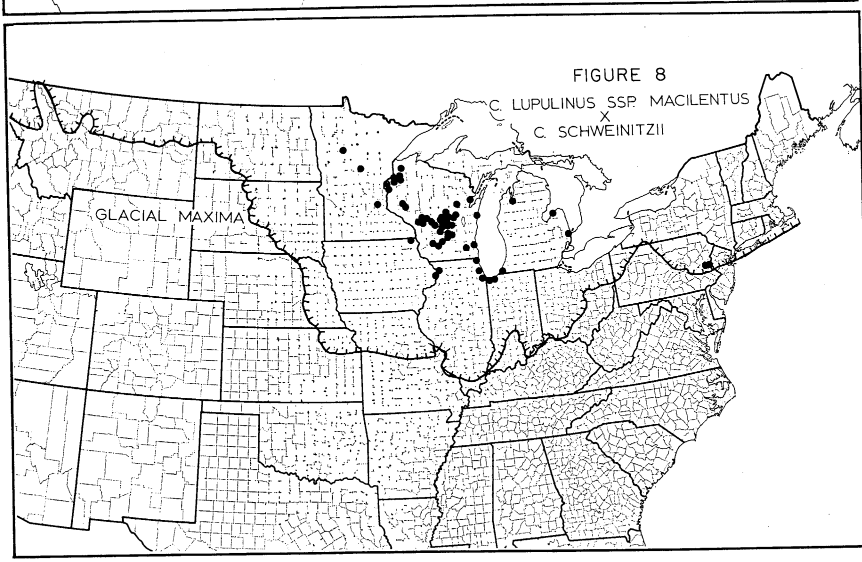
11b. CYPERUS LUPULINUS (Spreng.) Marcks ssp. MACILENTUS (Fern.) Marcks × C. SCHWEINITZII Torr. Map 13, Fig. 8.

Usually resembling *C. Schweinitzii,* but mostly smaller and more slender with fewer rays, more divergent-spreading involucral bracts, smaller achenes, and only slightly scabrous culms; often with low seed set. These highly variable hybrids center on the region of parental sympatry in the Great Lakes region (Figs. 3, 4 and 7), in Wisconsin occurring on sandstone outcrops and in dry exposed sands of roadcuts, sandblows of sand prairies, abandoned fields and young pine plantations. Hybrid scatter diagrams of local populations (including specimens of the highly fertile putative stabilized hybrid, *C. Houghtonii*) often show a rather complete bridge of variously intermediate forms connecting the parental taxa (Fig. 6). Flowering and fruiting synchronously with the parents. Diakinesis and metaphase I configurations have several ring complexes which do not permit accurate chromosome counts (Marcks, 1972).

12. CYPERUS HOUGHTONII Torr. Map 14, Fig. 9.
Houghton's Cyperus

Erect perennials 6–45 cm high, in small loose tufts borne from a cluster of hard, subglobose, corm-like rhizomes. Culms 3-angled, *smooth,* 0.5–1.5 mm thick at the apex. Blades 1–6 mm wide,





FIGURES 7 AND 8. Distribution maps of *Cyperus lupulinus* ssp. *lupulinus* X *C. Schweinitzii* and *C. lupulinus* ssp. *macilentus* X *C. Schweinitzii*.

scabrous-margined; involucral bracts blade-like, divergent. Inflorescence with a small dense cluster of terminal spikes and usually also with 1–8 unequal, obliquely ascending pedunculate rays up to 8 cm long. Spikelets subdigitate from a short rachis 2–5 mm long, 3-18-flowered, 4–15 mm long, 2.5–3 mm wide. *Scales rotund,* 2.0–2.5 mm long; keel broad and green; laminae traversed by 3–4 prominent nerves, the margins spreading or clasping. *Achenes broadly ovoid, rounded at both ends, the sides markedly concave,* 1.6–1.9 × 1.0–1.4 mm, dark brown.

A species narrowly restricted to dry exposed sands of "Jack Pine" *(Pinus Banksiana)* barrens in glaciated eastern North America (Fig. 9), in Wisconsin occurring mostly north of the Tension Zone in pure sands of glacial lake beds and outwash plains. Extensive population studies (Marcks, 1967, 1972), including morphologic, cytologic and chromatographic analyses, indicate *C. Houghtonii* to be of backcross hybrid origin to *C. lupulinus* ssp. *macilentus,* selected out of postglacially formed hybrid swarms of *C. lupulinus* ssp. *macilentus* and *C. Schweinitzii.*

Natural disturbance resulting from wind throw and fire have provided dry exposed sands suitable for establishment of plants of the *C. lupulinus* ssp. *macilentus*-*C. Schweinitzii* complex in the "Jack Pine" barrens essentially since glacial recession (Curtis, 1959). Because these glacial habitats are surely different and per-

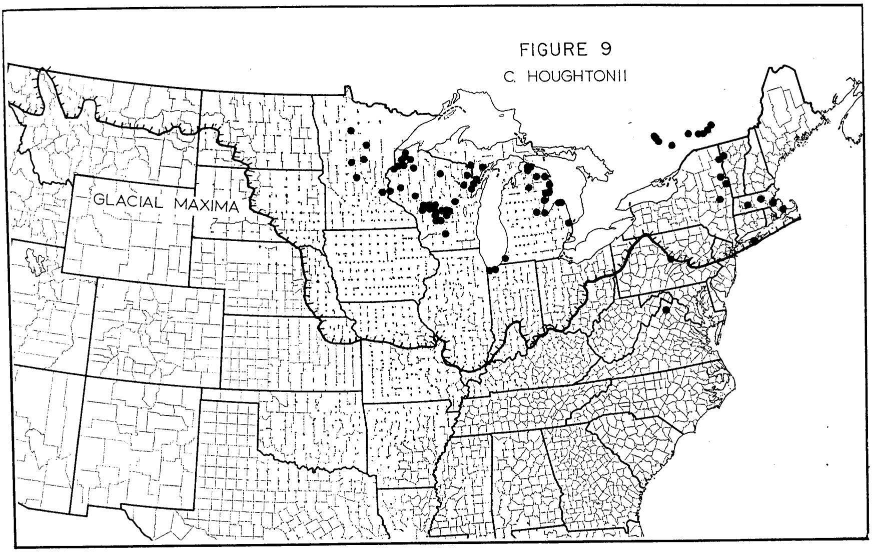
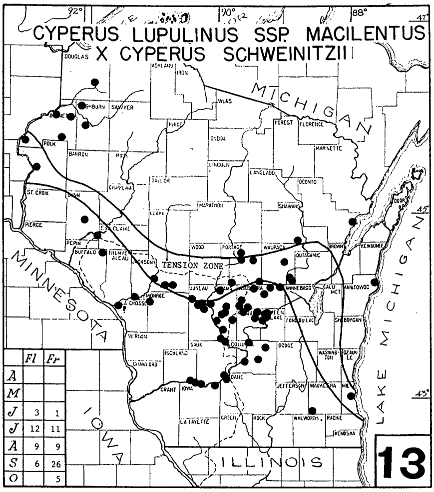
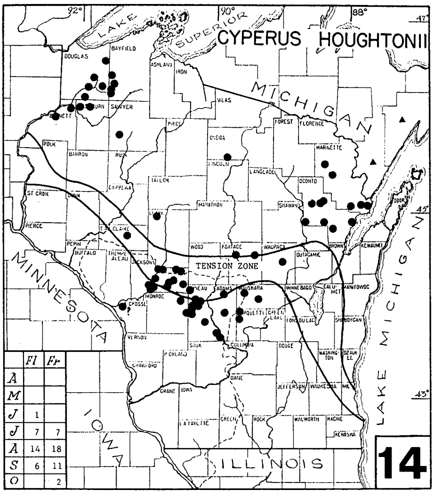


FIGURE 9. Distribution map of *Cyperus Houghtonii.*





haps somewhat intermediate to those in which the parental stocks have had long adaptive histories south of the glacial maxima, one might expect that new adaptive genotypes could have been selected out of hybrid swarms in the naturally disturbed "Jack Pine" barrens. Stabilizing selection acting on hybrid swarms has thus apparently allowed *C. Houghtonii* to evolve and exploit a new ecological niche to which neither of its parents is as well adapted.

The restriction of *C. Houghtonii* to glaciated territory with the exception of a once collected and presumably adventive station from Luray, Virginia, constitutes an anomalous distribution suggestive of a postglacial origin. With rare exceptions, all species present in glaciated territories of eastern and central North America have at least part of their range outside the Wisconsin glacial maxima where we may assume they survived the Wisconsin glaciation. The rare exceptions include some species of *Solidago* and other poorly understood microspecies of hybrid derivatives of large, actively evolving genera, some microspermous species (*Thismia americana, Cypripedium arietinum*), which may have been introduced by stratospheric dispersal from the Old World, various arctic and boreal elements, which may have survived on or near the ice sheet, and several Great Lake dune microendemics (Guire and Voss, 1963; Johnson and Iltis, 1963; Mickelson and Iltis, 1966). A postglacial hybrid origin for *C. Houghtonii* is thus suggested on grounds of its narrow restriction to glaciated territory. Flowering from July to October, fruiting from mid-July to mid-October (n = ca. 84, 85, 86; Marcks, 1972).

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ANTIMYCIN—BEYOND TELEOCIDE

Mary Ellen Antonioni
University Wisconsin—Madison

ABSTRACT

Two species of clams, *Lampsilis siliquoidea* and *Elliptio dilatatus*, were exposed to each of 4 dosage levels of antimycin (5, 10, 12, and 15 parts per billion antimycin/water) at three temperatures (17 C, 22 C, and 27 C). Each temperature test constituted a "run" of 27 days, during which the organisms were observed and dieoff recorded. The pH was a constant 7.5 and general water quality constant. At run III (27 C), fluorescein dye (used as a tracer dye with antimycin) was also tested alone and in combination with 15 ppb antimycin.

For both species, increase in dieoff as temperature increased was significant for 12 ppb and 15 ppb, but not for 5 or 10 ppb. There was an overall significant increase in dieoff as temperature increased. A comparison among 15 ppb antimycin, 15 ppb antimycin plus fluorescein, and fluorescein alone, yielded the following results: There was no significant difference in dieoff between the 15 ppb antimycin and 15 ppb antimycin plus fluorescein; there was no dieoff for fluorescein dye alone.

The *increase* in dieoff with increasing temperature was significantly greater for *L. siliquoidea* than for *E. dilatatus* for dosages 5 and 10 ppb. The total number of dead individuals after 27 days was significantly greater for *L. siliquoidea* than for *E. dilatatus* at 22 C and 27 C, but not at 17 C.

INTRODUCTION

Reclamation of streams, ponds, or lakes is the control of "undesirable" species of fish with materials and methods for eradicating such fish, either selectively or totally with subsequent replacement by "desirable" species. Undesirable species are defined as those with little or no commercial or sport fishing value; for example, carp (*Cyprinus carpio*), green sunfish (*Lepomis cyanellus*), stunted yellow perch (*Perca flavescens*), etc.

A number of management methods for thus reclaiming streams or lakes have been tried with little success; such methods include drainage, seining, and trapping of undesirable species. More recently, poisoning of such habitats with various teleocides has been attempted with greater success, but not without added problems of endangering non-target species of fish, other aquatic life and non-aquatic life present in, or dependent upon, the aquatic habitat.

One such teleocide is antimycin, which is being widely used primarily as a single management tool. This practice unwisely reduces complicated aquatic ecosystems to the few component parts which are able to withstand its effects. To date, few adequate studies have been made regarding the effects of antimycin on non-target organisms, on the reproductive success of organisms which do survive, or on post-treatment productivity of ecosystems which have been altered and simplified by its use. The present study is but one of many needed to thoroughly evaluate antimycin as a teleocide.

At the University of Wisconsin in the Department of Plant Pathology, Leben and Keitt (1948) noted that a culture of the apple scab fungus *Venturia inequalis*, was markedly inhibited by a white, slow-growing, actinomycete contaminant. An antibiotic was isolated and discovered to be particularly effective against fungi and hence was named antimycin.

A new phase of antimycin research began in 1963 when Derse and Strong (1963) reported that fish were extremely sensitive to the antibiotic. The Wisconsin Alumni Research Foundation, which did much of the original research on antimycin as a teleocide, licensed Ayerst Laboratories, New York, a division of American Home Products Corporation, to produce and market antimycin. This product, under the tradename of "Fintrol", has been approved for use in fresh water fish management and is registered as a teleocide by the United States and Canadian governments. (Radonski and Wendt, 1966).

There are three registered formulations of antimycin presently available (Lennon, et al., 1971). Fintrol-5 consists of antimycin coated on sand grains in such a way as to release the toxicant evenly in the first 5 feet of water as the sand sinks; Fintrol-15 which releases it in the first 15 feet of depth, and a liquid, Fintrol Concentrate, which was developed for use in very shallow running waters and streams.

Experiments are being conducted on a fourth type of antimycin, a cake form, that can be suspended in streams to release a specific amount of the toxicant at a certain rate.

The qualities of antimycin which make it attractive as a teleocide can be summarized as follows: It is relatively specific to fish, i.e., fish-killing concentrations are considered harmless to other aquatic life, waterfowl and mammals. It is effective in small concentrations against all life stages of fish, egg through adult. Its respiratory inhibiting properties are irreversible at lethal dosages.

It is odorless and colorless in water and does not repel fish from treatment areas. Thus, it is the first fish toxicant to lend itself well to partial or spot treatments of lakes. It can also be used somewhat selectively against target species in certain circumstances (Radonski, 1967; Burress and Luhning, 1969). Antimycin degrades rapidly in water, usually within 4 days or sooner where pH is high. When necessary, it can be detoxified in water by addition of potassium permanganate (Berger, et al., 1969).

The treatment of the Rock River drainage system in Wisconsin with antimycin is the largest reclamation project attempted thus far using antimycin as a single management tool. Two hundred-and-seventy-four miles of stream (East branch, Rock River) and four impounded ponds were treated at the outset of the reclamation in 1971. Another 226 miles of stream and over 30,000 acres of impounded waters (including the nationally known Horicon Marsh, Dodge County, Wisconsin) were in the process of being treated as of the date of this writing.

In a post-treatment survey of the East Branch of the Rock River in Dodge County, it was discovered that mussels were apparently one of the non-target species greatly affected by antimycin treatment (Bratley and Mathiak, 1971). Due to the unavailability of the above reference, it is reiterated here in some detail. It can be found in its entirety in the Environmental Impact Statement, August, 1973, submitted to the State of Wisconsin by the Department of Natural Resources.

The study area was located on the East Branch of the Rock River, a quarter mile south of Allenton, Wisconsin. It extended upstream for 380 feet. Here, the stream was near the upper reaches of the East Branch, ranging from 8 to 12 feet in width and 6 to 18 inches in depth. The bottom was firm and gravelly, though overlain with thick layers of silt.

Sampling was begun 8 days after antimycin treatment at which time the water was very clear. The study continued for 40 days after treatment, after which mortality was too low for further sampling.

The entire area was traversed by two biologists walking abreast upstream collecting all mussels lying on the stream bottom which had died after treatment. Only those which still had parts of the viscera intact were collected. Empty *shells were not* included in the mortality counts. There was a total of 8 collections made within a month (August 19, 1971–September 20, 1971). Near the downstream end of the study area, a 25-foot section was measured off wherein the bottom substrate was thoroughly hand-grubbed for both live and dead mussels. The dead mussels were collected and the live specimens were counted, identified, and returned to the stream. This section was sampled at three separate times to determine remaining species and numbers. Two other 25-foot sections, one approximately a half mile and the other about three-fourths mile upstream to the study area were hand-grubbed thoroughly two months after treatment for live mussels to determine survival in a different area. A one-inch wire mesh fence was placed across the stream at either end of the study area for two days during the time of peak mortality. The object was to catch any mussels which may have drifted into or out of the study area and thus bias the study. This method showed that drifting shells were insignificant.

The mussels were prepared for identification by removing the viscera with a knife and cleaning the shells to remove algae and other detritus adhering to the shells. Mr. Billy G. Isom, a mussel expert from Mussel Shoals, Alabama, assisted in the field identification of all individuals recovered.

Eleven species of clams were found to inhabit the 380-foot study area, and, roughly approximated, made up a population of about 1200 individuals. Forty days after the treatment with antimycin, approximately 62% mortality had occurred in this population. The peak mortality rate for the population occurred 16–19 days after the treatment, but four peak mortality periods were noted: immediately or shortly after treatment for *Lampsilis siliquoidea* (fat

TABLE 1. NUMBERS OF NEWLY DEAD CLAMS FOUND IN THE 380-FOOT STUDY AREA OF THE EAST BRANCH OF THE ROCK RIVER AT ALLENTON AFTER ANTIMYCIN TREATMENT*

Species	Days Post-Treatment							
	8	12	16	19	22	27	33	40
Alasmidonta calceolus	23	7	49	79	29	0	0	0
Alasmidonta marginata	0	3	0	0	0	0	0	0
Anodonta grandis	12	15	12	2	2	0	0	0
Anodontoides ferussacianus	3	17	41	44	23	4	0	0
Amblema plicata	0	1	16	8	8	8	4	1
Elliptio dilatatus	2	8	14	12	14	32	17	12
Fusconia flava	0	0	3	8	4	12	0	0
Lampsilis siliquoidea	36	34	19	12	2	1	0	0
Lasmigona complanata	0	1	9	10	5	2	0	0
Leptodea fragilis	0	1	0	0	1	0	0	0
Strophitus rugosus	0	24	26	5	3	0	0	0
TOTALS	76	111	189	180	91	59	21	13

*The treatment date was 8/11/71

mucket) and *Andonata grandis* (floater); 16 days after for *Amblema plicata* (three-ridge) and *Strophitus rugosus* (squaw foot); 19 days after for *Alasmidonta calceolus* (slipper shell), *Anodontoides ferussacianus* (cylindrical paper shell), and *Lasmigona complanata* (white heel-splitter); and 27 days after for *Elliptio dilatatus* (lady finger), and *Fusconia flava* (pig toe). Numbers of the two remaining species, *Alasmidonta marginata,* and *Leptodea fragilis,* were too small to place in any of these categories. *Alasmidonta calceolus* was eliminated from the study area by the 27th day after treatment. Representatives of *Elliptio dilatatus* and *Amblema plicata* survived best in the study area (See Table 1).

The study suggests: 1) that mussels are apparently affected by antimycin; 2) that response rates are different for different species; 3) that mussels are affected over a long period of time; 4) that the response is delayed (i.e. the mussels do not appear to be immediately affected); and 5) that mussels are apparently affected at fairly low dosages (i.e., at fish-killing concentrations).

It was the intent of the present study (in a controlled laboratory experiment, eliminating field variables) to ascertain whether or not the dieoff of mussels was a direct effect of exposure to antimycin and/or its tracer dye, fluorescein, or some other factor.

METHODOLOGY

Experimental Population

Due to the inability to collect large numbers of any one species of mussel, two species were purchased from NASCO Biological Supply Co. in Fort Atkinson, Wisconsin. *Lampsilis siliquoidea* and *Elliptio dilatatus* were identified and chosen because of their availability, recent collection from an untreated area (White River, Wisconsin), and because both species are native to the Rock River drainage system. Also according to Bratley and Mathiak, 1971, *L. siliquoidea* was relatively quickly affected following treatment with antimycin whereas *E. dilatatus* did not succumb until considerably later; thus providing two ranges of tolerance to compare when describing mortality patterns.

The mussels were transported to Madison, Wisconsin, and held in a stream tank at 10 C for the duration of the experiment. The holding tank was a large "living stream" aquarium with circulating tap water cooled to 10 C. The organisms were not fed or maintained in any other fashion; this was in keeping with conditions suggested by the NASCO Biological Laboratory.

Individuals were taken as needed, at random, for treatment. All individuals of both species were of uniform size, shape, and color, and appeared to be typical individuals for their species.

Experimental

The experiment was carried out at the Biotron, University of Wisconsin, Madison, because of the necessity of maintaining aquaria at constant temperatures. A large concrete water bath was constructed for this purpose, with water of a given temperature pumped into the bath and circulated around the aquaria which were placed on angle irons to allow circulation underneath as well. The aquaria were identical 20-gallon, slate bottom tanks, furnished by the Nevin State Fish Hatchery, Madison, Wisconsin.

The aquaria were entirely covered with a plastic sheet which was folded back only to make observations. Each tank was aerated with a tube and airstone. The purpose of the cover was to prevent evaporation as much as possible, as it was thought that addition of water during the experiment could affect the level of the antimycin in the treatment aquaria (i.e. evaporation of the water would alter the parts per billion ratio initially ascribed to each aquarium). The study area was brightly lighted with fluorescent tubes automatically controlled to provide 12 hours of "daylight" and 12 hours of darkness. The room was kept at a constant 10 C in order to simplify the mechanics of providing the necessary water bath temperatures, it being easier to heat the water bath against a cool gradient than to cool it against a warmer room.

Experimental Conditions

Twelve individuals of each species were exposed to each of 4 treatment levels of antimycin at three temperatures (each temperature series constituting a "run" of 27 days) at a constant pH of 7.5, and observed for dieoff on a daily basis.

The dosage levels used were as follows: Dosage level Control = 0 ppb (parts per billion antimycin/water); Dosage level 2 = 5 ppb; 3 = 10 ppb; 4 = 12 ppb; and 5 = 15 ppb. The temperatures were 17 C for Run I, 22 C for Run II, and 27 C for Run III. Additional conditions for the third temperature run are described below.

In order to conserve mussels, it was decided to run the tracer dye tests at Run III only (27 C). Two additional treatment aquaria were set up using fluorescein dye alone and fluorescein dye with 15 ppb antimycin. The amount of fluorescein used was based on calculations for 11 gallons of water per information from Mr. William Selbig, Fisheries Biologist, Department of Natural Resources. The 27 C and 15 ppb antimycin were chosen as criteria for the additional tracer dye tests because these conditions best approximate the actual treatment conditions in the Rock River reclamation project (personal observation, pre- and post-treatment survey of the East Branch, Rock River, summer, 1969; and personal communication with Mr. William Selbig, Project Director, Rock River Hearing, Juneau, Wisconsin, Spring, 1971).

Twelve individuals of *L. siliquoidea* and 12 individuals of *E. dilatatus* were exposed to the two additional treatments and observed for dieoff during the 27-day period for Run III.

The dosage and temperature criteria outlined above for all runs were chosen because they best approximate those conditions actually being used in field treatments, and those used for similar experiments with fish, from which a great deal of our available information about the effects of antimycin has been derived.

An exposure limit of 27 days was chosen because it was a long enough period of time and yet not so long as to jeopardize the validity of the results by stressing the mussels through unnecessarily long exposure to unnatural habitat conditions; i.e., aquarium life, lack of food, etc. The time of 27 days was also given as the peak dieoff time for *Elliptio* individuals (Bratley and Mathiak, 1971).

The two main independent variables were dosage level and temperature. The pH, another important correlate to the lethality of antimycin, was held at a constant 7.5. It has been observed that pH does not fluctuate greatly for the types of warm-water stream habitats which have been treated in the Rock River drainage system, but remains between a maximum of 8.2 and a minimum of 7.5 (personal communication with Mr. William Selbig). The present experiment was carried out at pH of 7.5; it neither increased nor decreased throughout the experiment, and was unaffected by the presence or absence of the experimental organisms. Analyses other than pH were not made of the water used in this experiment. However, an extensive analysis of the Biotron tap water was made by the Wisconsin Alumni Research Foundation in March, 1972 (see Table 2), and the main parameter of concern for the present study was pH.

The dependent variable was dieoff, which was recorded on a daily basis for both species, throughout the three 27-day runs.

Antimycin Formulation Used

The liquid Fintrol Concentrate of antimycin (furnished by Ayerst Laboratories) was used for the experiment. Liquid Fintrol is the formulation for treatment of shallow running waters such as the Rock River drainage system.

An initial stock solution of antimycin was prepared at the outset of the experiment to ensure uniformity, and, in order to prevent degradation and activation, it was mixed with an acetone retainer

TABLE 2. ANALYSES OF WATER SAMPLES TAKEN IN BIOTRON, UNIVERSITY OF WISCONSIN, MADISON, MARCH, 1972

		Cold Water	Softened Hot Water
Calcium	ppm	80.5	2.00
Magnesium	ppm	46.0	0.67
Sodium	ppm	9.6	136.00
Iron	ppm	.038	0.018
Manganese	ppm	0.006	0.005
Chlorides	mg/l	21.2	7.7
Sulfates	ppm	85.2	66.6
Fluorides	ppm	1.1	1.0
Total dissolved Solids	mg/l	530.0	512.0
Residual Chlorine	ppm	0.10	0.10
pH		7.35	7.50
Total hardness as $CaCO_3$	mg/l	388.0	7.80
Alkalinity			
Phenolphthalein as $CaCO_3$	mg/l	0	0
Methyl Orange		310.0	306.0

solution (per instructions from Ayerst Laboratories) until ready for addition to the treatment aquaria. The formula for determining the amounts of antimycin stock solution to add to water in order to arrive at desired concentrations in parts per billion, was as follows:

$$[A]\ [B]\ [.35] = C$$

where

A = Number of gallons of water in aquarium
B = Desired concentration in parts per billion
C = Milliliters of stock solution to add to treatment aquaria
.35 = Conversion factor for gallons to milliliters

The stock solution was prepared by taking 5 milliliters of the acetone/antimycin solution and diluting it in 1 gallon of water (procedure suggested by Ayerst Laboratories). It was also suggested that at least 10 gallons of water be used in the treatment vessels in order to ensure proper mixing of the solution; hence, 11 gallons of water was used for all calculations in the present study.

The Tracer Dye

Standard fluorescein dye ($C_{20}H_{12}O_5$) was obtained from the Aldrich Chemical Company in Milwaukee, Wisconsin, and added to the appropriate acetone/antimycin milliliter solution to obtain 15 ppb antimycin and fluorescein. The dye was also added to the acetone solution alone to provide proper dissolution when added to water for the fluorescein test without antimycin.

RESULTS

Experimental Analyses

In a one-way analysis of variance procedure according to Hayes (1963), a null hypothesis of no difference in dieoff due to treatment with antimycin (across dosages, within temperatures) was tested and rejected at the .05 level of significance (See raw data Tables 3, 4, and 5, and summary Table 6.) A separate one-way analysis of variance was performed for the 27 C data, which included two additional treatment blocks [i.e., antimycin at 15 ppb plus fluorescein (D_6), and fluorescein dye alone (D_7)]. A null hypothesis of no difference due to treatment with antimycin was tested for D_1 (Control), D_5, D_6, and D_7, for both species, and rejected at the .05 level (See summary Table 7).

Following the overall F-test results, individual pairwise comparisons of interest were made according to a post-hoc test between means (Scheffe, 1959).

A graph of the parameters (number of individuals dead versus dieoff day) indicated that these two parameters were dependent and thus either could be chosen as the parameter for the analysis of variance tests. Since the observations made in this experiment were carried out over a specified time of 27 days, there was some question as to whether an analysis of variance procedure could be used for the data. But the fact that 27 days is extremely short compared to the life expectancy of clams, indicates that the termination of observations after this time would not invalidate the analysis of variance approach. It was further decided to look at the average dieoff times at the various treatment criteria. Days for which dieoff was observed were converted to logarithmic functions for a more accurate estimation of the average dieoff day and for conciseness of graphing (See Tables 8 and 9).

Results

Following the overall F-tests performed on the data, several post-hoc comparisons (using dieoff as the parameter) were made and tested for significance at the .05 level.

For both species, increase in dieoff as temperature increased, was significant for 12 ppb (D_4) and 15 ppb (D_6), but not for 5 ppb (D_2), or 10 ppb (D_3). There was an overall significant increase in dieoff as temperature increased.

At Run III (27 C), a comparison between 15 ppb (D_5), and 15 ppb antimycin plus fluorescein (D_6), yielded no significant difference in dieoff for either *L. siliquoidea* or *E. dilatatus.*

The increase in dieoff for *L. siliquoidea* was significantly greater than the increase in dieoff for *E. dilatatus* for D_1 — D_5. The total

TABLE 3. RAW DATA FOR RUN I (17 C). NUMBER DEAD OUT OF TOTAL EXPOSED (12 INDIVIDUALS AT EACH DOSAGE)

	L. siliquoidea					E. dilatatus				
Dieoff Day	D_1	D_2	D_3	D_4	D_5	D_1	D_2	D_3	D_4	D_5
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12			1					1	1	
13		1			1					
14										
15								1		
16										
17										
18										
19										
20		1								
21										
22										
23										
24		1								
25										
26										
27										
TOTALS	0	3	1		1			2	1	

D_1 = 0 ppb (parts per billion antimycin/water; Control)
D_2 = 5 ppb
D_3 = 10 ppb
D_4 = 12 ppb
D_5 = 15 ppb

number of dead individuals was significantly greater for *L. siliquoidea* than for *E. dilatatus* at 22 C and 27 C, but not at 17 C.

The following observations (using average dieoff day and number of dead individuals for each day as parameters) were made, though not tested for statistical significance:

TABLE 4. RAW DATA FOR RUN II (22 C). NUMBER DEAD OUT OF TOTAL EXPOSED (12 INDIVIDUALS AT EACH DOSAGE)

	L. siliquoidea					E. dilatatus				
Dieoff Day	D_1	D_2	D_3	D_4	D_5	D_1	D_2	D_3	D_4	D_5
1										
2										
3										
4										
5										
6										
7										
8										
9			1		1					
10										
11			1							
12	1									
13										
14										
15										
16										
17		1	1		1		1			
18										
19										
20										
21				1	1					
22										
23					1					
24										
25										
26				1	1					
27										
TOTALS	1	1	3	2	5		1			

D_1 = 0 ppb (parts per billion antimycin/water; Control)
D_2 = 5 ppb
D_3 = 10 ppb
D_4 = 12 ppb
D_5 = 15 ppb

The only remarkable change in the average dieoff day as temperature increased was for *L. siliquoidea,* for which a decrease of 10.2 days is noted between 22 C and 27 C (See Table 9). Increase in dosage did not greatly affect the average dieoff day for either species. The average dieoff day for *E. dilatatus* was greater

TABLE 5. RAW DATA FOR RUN III (27 C). NUMBER DEAD OUT OF TOTAL EXPOSED (12 INDIVIDUALS AT EACH DOSAGE)

	L. siliquoidea							E. dilatatus						
Dieoff Day	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_1	D_2	D_3	D_4	D_5	D_6	D_7
1														
2		2	1	2	1	1						2		
3			1	1	1									
4			1		2	1								
5														
6					1									
7						1								
8					1									
9						1							2	
10					1	1								
11			1											
12														
13											1			
14														
15														
16														
17														
18		1							1			1	1	
19				1								1	1	
20					1							1	1	
21													1	
22					1	1						1		
23														
24				1		1						1		
25					1	1								
26					1					1		1	1	
27													1	
TOTALS	0	3	4	5	11	8	0	0	1	1	1	8	8	0

D_1 = ppb (parts per billion antimycin/water; Control)
D_2 = 5 ppb
D_3 = 10 ppb
D_4 = 12 ppb
D_5 = 15 ppb
D_6 = 15 ppb Antimycin plus fluorescein tracer dye
D_7 = 0 Fluorescein tracer dye

than for *L. siliquoidea* at 27 C, but was essentially the same for 22 C and slightly lower at 17 C.

It was evident from the present study that antimycin is harmful to mussels not only at relatively small dosages, but over a long

TABLE 6. SUMMARY TABLE FOR ONE-WAY ANOVA OVER ALL DATA

Source	SS	df	MS	F
Dosage (Between)	692.4	(J—1) 4	173.1	4.24*
Temperature (Within)	408.0	(N—J) 10	40.8	
TOTALS	1100.4	14	213.9	

*Significant at .05 level.

TABLE 7. SUMMARY TABLE FOR ONE-WAY ANOVA AT RUN III (27 C WITH TWO ADDITIONAL TREATMENT BLOCKS)

Source	SS	df	MS	F
Dosage (Between)	148.5	(J—1) 3	49.5	30.96*
Species (Within)	5.0	(N—J) 4	1.25	
TOTALS	153.5	7	50.75	

*Significant at .05 level.

TABLE 8. AVERAGE DIEOFF DAYS FOR TOTAL INDIVIDUALS AT ALL DOSAGES

Temperature	Species	Total Number Dead	Average Dieoff Day
17C	L. siliquoidea	5	15.7
17C	E. dilatatus	3	12.9
22C	L. siliquoidea	12	16.3
22C	E. dilatatus	1	17.0
27C	L. siliquoidea	23	6.2
27C	E. dilatatus	10	16.1

period of time. Whether or not there is some physiological condition unique to the clam which would make its utilization of antimycin different from that of other organisms is a question beyond the scope of this study. Its intent was simply to eliminate as many field variables as possible and concentrate on whether or not there was dieoff as a direct effect of exposure to antimycin at differing dosages and temperatures.

DISCUSSION

While there seem to be some advantages to the use of antimycin (especially when compared to what else is available), it is the author's opinion that there are many loose ends regarding the

TABLE 9. AVERAGE DIEOFF DAYS AT EACH DOSAGE

Temperature 17C				
	Lampsilis siliquoidea		Elliptio dilatatus	
Dosage	No. Dead	Average Day	No. Dead	Average Day
D_1	0	----	0	----
D_2	3	18.3	0	----
D_3	1	12.0	2	13.3
D_4	0	----	1	12.0
D_5	1	13.0	0	----

Temperature 22C				
	Lampsilis siliquoidea		Elliptio dilatatus	
Dosage	No. Dead	Average Day	No. Dead	Average Day
D_1	1	12.0	0	----
D_2	1	17.0	1	17.0
D_3	3	11.9	0	----
D_4	2	23.2	0	----
D_5	5	18.0	0	----

Temperature 27C				
	Lampsilis siliquoidea		Elliptio dilatatus	
Dosage	No. Dead	Average Day	No. Dead	Average Day
D_1	0	----	0	----
D_2	3	4.2	1	18.0
D_3	4	4.1	0	----
D_4	5	5.6	1	13.0
D_5	11	8.5	8	11.8
D_6	8	9.5	7	16.2
D_7	0	----	0	----

research that should be done before a toxicant such as antimycin is used as a single management tool in the environment.

There have been few exhaustive studies on the effects of antimycin on non-aquatic and aquatic life other than fish. Antimycin has also been used in conjunction with other fish toxicants (e.g. rotenone) ; but the effects of such interactions have not been carefully studied. Howland (1969) studied the interaction of rotenone and antimycin in fish bioassay experiments. It was concluded that the toxicity of antimycin and rotenone together is greater than either used alone; that is, the two chemicals when used in combination appear to have an additive effect (though not concluded to be synergistic).

A few studies have been done regarding effects of antimycin on mammals, and one or two attempts have been made to determine whether there are any harmful effects from antimycin residues in tissues of fish consumed by humans. Herr, Greselin, and Chappel (1968) studied the toxicity of antimycin and its degradation products to mammals. Hematologic, organ, and tissue studies were made on rats which were fed varying doses of antimycin for different periods of time. In oral administration, they concluded that the toxicity of antimycin was quite low for mice, rabbits, and quail, but that it was lethal for guinea pigs at comparable dosages.

When injected intraperitoneally, however, the toxicity was about 0.18 mg/kg body weight. Infusion in dogs at the rate of 10 micrograms/kg/min. was fatal. In a study of the oral administration effects of antimycin on reproduction in rats, it was found that no observable changes occurred during pregnancy but three weeks after weaning, pups born to treated parents weighed 10% less than those born to control parents. Skin and eye irritations were noted in rats and rabbits, when antimycin was applied topically to these areas (Herr, et al., Ibid).

Suggestions and Implications For Further Research

Baker (1928) has suggested that the nature of the water in which mussels live profoundly influences them for good or ill. For example, changes in micro-fauna, vegetation, siltation, or turbidity might adversely affect a mussel population in short periods of time, to say nothing of longer range effects by elimination of fish hosts or interruption of fish-host specificity. Mussel glochidia "react to certain species of fish and will not complete metamorphosis on others. . . . When we consider that only a relatively small number of species of fish are susceptible to infection by glochidia, it becomes evident that there must be a definite ecological relationship between the fish and parent mussel, such that both must frequent the same kind of environment at the same time when the glochidia are ready to be discharged." Glochidial infection has also been shown to give immunity against infection by more serious parasites, thus benefiting the host fish (Baker, 1928).

It is also generally conceded that mussels, because of their sensitivity to pollution, are good indicator species for monitoring degrees of degradation in streams or lakes. Since mussels are generally confined to a particular portion of a lake or stream (a mussel shoal), they have been used extensively to measure fallout and pesticide content, as well as other forms of water pollution (Van Der Schalie, 1970). Thus, clams can be used as indicators of some of the changes brought about in a river system by human activity.

It is the suggestion of the author that replications of the present study (varying pH, etc.), followup studies and similar studies with other organisms be done to determine the exact nature of the detrimental effects of antimycin.

The present study has shown that mussels are killed by antimycin. The next logical step would be to find out why. Perhaps there is something unique to the physiology of the clam which makes it sensitive to antimycin in fairly low dosages; perhaps the respiratory system of the clam is unique in its method of assimilation, storage, or utilization of antimycin; perhaps the fact that clams are filter feeders has an effect on how much antimycin is taken by the organism.

Hopefully, answers to questions like these will help provide us with vitally needed information about the mode of action of antimycin in a variety of organisms.

Those agencies responsible for alterations in the environment such as are brought about by use of toxicants should be aware of the fact that they may be unable to "clean up their mess." Losses in the biota are irreversible and the alterations will leave gaps in inter-relationships of flora and fauna, as well as in the opportunities for studying unaltered ecosystems.

Stream ecosystem dynamics must be evaluated more carefully and exhaustive attempts made to discover rare and unique species. The calculation of correct dosages for streams or lakes with diverse temperatures, fauna, flora, pH, etc., should be more accurately gauged to ensure annihilation of target species only. In a management report for the Department of Biological Sciences, University of Idaho, Moscow, Idaho, Rabe and Wissmar, 1969, cautioned that more research is necessary to refine recommended concentrations of antimycin under varied environmental conditions. Even 10 days post-treatment at 5 ppb, trout fry exposed to the oligotrophic lake (at 19 C and pH near neutrality), die within 12 hours. The fry were observed to be in distress less than an hour after the distribution of the poison and some were dead in less than 1.5 hours. Thirteen days after the poisonings, no living crustaceans were found in the lake samples.

The effects of removal of forage species and rates of growth of introduced species should be determined over a long period of time in reclamation projects. A long-range cost/benefit analysis should then be attempted to evaluate the success of such large-scale management programs.

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ARBOVIRAL ANTIBODY SURVEY OF WILD MAMMALS IN SOUTHEASTERN WISCONSIN

Omar M. Amin and Wayne H. Thompson
University Wisconsin—Parkside and —Madison

ABSTRACT

A survey of host-ectoparasite-pathogen systems was undertaken in a study of a partially forested area in southeastern Wisconsin between April and October 1972. Sera of 17 species of small and medium sized wild mammals were screened for antibodies with antigens for Eastern, Western, St. Louis, Powassan, California, and Bunyamwera group viruses. Results of tests with all sera were negative, except for one from a gray squirrel which had a low titer HI reaction with Western encephalitis virus. Antibodies to La Crosse virus, associated with California encephalitis in southwestern Wisconsin and commonly found in chipmunks and squirrels there, were not found in this southeastern Wisconsin area.

INTRODUCTION

A definite relationship exists among disease pathogens, arthropod vectors, and vertebrate host systems. The present study was designed to obtain information on the ecological role played by southeastern Wisconsin arthropods and wild mammals in the maintenance and dissemination of vector-borne diseases of man and animals in nature. The primary stimulation came from the fact that certain viral disease of man, i.e., California encephalitis, La Crosse strain, has consistently been reported from southwestern Wisconsin, Thompson and Inhorn (1967) and Moulton and Thompson (1971), while no cases have been implicated as being infected in the southeastern corner of the state. It was not known whether cases did not actually occur in the southeast, or whether they were overlooked. The main known vertebrate hosts (gray squirrels and chipmunks) and mosquito vector *(Aedes triseriatus)* are, however, common to both portions of the state (SE and SW).

The heavily populated southeastern portion was originally leveled by glaciers and consists of cultivated farmlands and a number of deciduous woodlots which often contain suburban or rural homes. These offer many opportunities for exposure of children to forest dwelling arthropods. The originally non-glacial southwestern portion of the state is a well drained upland region with forests mostly associated with hillsides and valleys. More information was needed on the differences in arthropod and mammal populations in these two areas as well as the pathogens that they harbor. The ecology of collected arthropods, host, and mosquito populations will be reported elsewhere.

MATERIALS AND METHODS

The study areas: The Parkside study area encompasses about 75 acres located in Kenosha County, north of the Pike River and south of County Road A, and about 2.5 miles (4 kilometers) west of the Lake Michigan shoreline. This ecological habitat consists of natural undisturbed stream-fed deciduous forested areas interspaced with lowland and upland prairies (Fig. 1). More prairies of similar composition and wood lots (wet, dry, and mesic) lie directly south (across the Pike River) and east of the above described study area. County Road A runs east-west directly north of the study area across which similar habitats as well as farm lands are located. A golf course partially separates the western boundaries of the study area from the larger deciduous forests (southern mesic) of Petrifying Springs Park.

Animal capture and examination: Havahart mammal live traps (sizes 1, 2, 3A) were set in 24 designated grids (Fig. 1) 3 per station, and were regularly operated for 3 consecutive days and nights every other week between April and October, 1972. A pilot study was earlier made in the same area during fall, 1971 (September, October). Traps were checked twice daily, at dawn and shortly before sunset. Captured animals were anesthetized with ether after being shaken out of the traps into cloth laundry bags. They were sexed, measured, weighed, tagged, and cleaned of ectoparasites. Blood samples were taken primarily by heart puncture with 3 or 5 ml. syringes and 18, 23, or 25 gauge needles, depending on the size of the animal, after which they were released. The samples were collected in 10 ml. screw cap tubes which were then promptly stored on wet ice until later centrifuged in the laboratory and serum and clot were each frozen in separate vials (—80°F.) for later antibody and isolation tests. Temperature, precipitation, and relative humidity in the study areas were regularly recorded.

Serology: Tests of sera for antibodies were conducted in the Zoonoses Research laboratory in the State Laboratory of Hygiene, Madison. Sera were screened in: (1) Hemagglutination-inhibition (HI) tests with antigens for Eastern equine encephalitis (EEE), Western equine encephalitis (WEE), St. Louis encephalitis (SLE), Powassan (POW), and Bunyamwera (BUN) group viruses. (2)

TABLE 1. SEROLOGICAL DATA ON PARKSIDE MAMMALS TESTED FOR EEE, WEE, SLE, POW, BUN, LAC, TVT, JC, SSH, 1971, 1972

Mammal species	Samples tested: H–I 1971	H–I 1972	TCNT 1971	TCNT 1972	Total H–I	Total TCNT	Test results (H–I and TCNT
Cottontail rabbit, *Sylvilagus floridans*	0	4 (4)[1]	0	4 (4)	4 (4)	4 (4)	----------
Eastern chipmunk, *Tamias striatus*	17 (16)	148 (122)	22 (20)	189 (144)	165 (138)	211 (164)	----------
Eastern fox squirrel, *Sciurus niger*	0	1 (1)	0	1 (1)	1 (1)	1 (1)	----------
Eastern gray squirrel, *S. carolinenses*	0	70 (57)	0	70 (57)	70 (57)	70 (57)	#261+ (1:10) for WEE in H–I (sampled 24 June 1972)
Franklin's ground squirrel, *Citellus franklini*	0	1 (1)	0	1 (1)	1 (1)	1 (1)	----------
Long tailed weasel, *Mustela frenata*	0	3 (2)	0	3 (2)	3 (2)	3 (2)	----------
Meadow jumping mouse, *Zapus hudsonius*	0	31 (31)	0	68 (67)	31 (31)	68 (67)	----------
Meadow vole, *Microtus pennsylvanicus*	2 (2)	0	6 (6)	0	2 (2)	6 (6)	----------
Norway rat, *Rattus norvegicus*	0	1 (1)	0	1 (1)	1 (1)	1 (1)	----------
Opossum, *Didelphis marsupialis*	3 (3)	28 (25)	3 (3)	28 (25)	31 (28)	31 (28)	----------
Prairie vole, *Microtus ochogaster*	0	2 (2)	0	2 (2)	2 (2)	2 (2)	----------
Raccoon, *Procyon lotor*	0	15 (14)	0	15 (14)	15 (14)	15 (14)	----------
Short tail shrew, *Blarina brevicauda*	2 (2)	0	3 (3)	0	2 (2)	3 (3)	----------
Striped ground squirrel, *Citellus tridecemlineatus*	0	1 (1)	0	4 (4)	1 (1)	4 (4)	----------
Striped skunk, *Mephitus mephitus*	1 (1)	0	1 (1)	0	1 (1)	1 (1)	----------
White footed mouse, *Peromyscus leucopus*	0	6 (6)	3 (3)	18 (18)	6 (6)	21 (21)	----------
Woodchuck, *Marmota monax*	0	1 (1)	0	1 (1)	1 (1)	1 (1)	----------
TOTAL	25 (24)	312 (268)	38 (36)	405 (341)	337 (292)	443 (377)	1

[1]Figures in parentheses represent the number of individual animals sampled.

Neutralization tests in BHK_{21} tissue culture cells (TCNT) with California encephalitis (CE) group; La Crosse (LAC), Trivittatus (TVT), Jamestown Canyon (JC), and Snowshoe Hare (SSH); and Bunyamwera (BUN) group (Wisconsin mosquito isolate #523). Sera which had been initially diluted upon sampling to 1:2, 1:3, or 1:5, were further diluted in the laboratory to a final 1:10 for use in the TCNT tests. Initial dilutions of 1:10 were not further diluted. For HI tests, only undiluted sera or those diluted 1:2 or 1:3 in the field were tested. They were each further diluted 1:10 during the acetone treatment prior to testing.

RESULTS AND DISCUSSION

A total of 335 and 441 sera from 292 and 377 different mammals of 17 species captured in the Parkside study area (September, October, 1971 and April–October, 1972) were screened in hemagglutination-inhibition and tissue culture neutralization tests, respectively. The results are shown in Table 1. We found no evidence of detectable antibodies neutralizing CE or BUN group viruses in sera of these mammals from the Parkside area, i.e., chipmunks and gray squirrels (Table 1), species which commonly have antibodies when collected from forests in southwestern Wisconsin. Sera neutralizing La Crosse virus from chipmunks and squirrels in southwestern Wisconsin were included as additional controls for the sensitivity of these tests.

CALIFORNIA ENCEPHALITIS

Human cases of CE in Wisconsin occur mostly in the western and southwestern parts of the state where forest dwelling mammals (mainly chipmunks and squirrels) and mosquitoes (primarily *Aedes triseriatus*) are involved in the natural cycle of La Crosse virus in nature (Thompson and Inhorn, 1967; Moulton and Thompson, 1971). That role has also been experimentally studied (Pantuwatana *et al.*, 1972). Isolates of La Crosse and other CE group viruses (TVT, SSH, JC) have also been obtained from pools of *Aedes triseriatus, A. communis* group, *A. trivittatus,* and *Culex pipiens* by Thompson *et al.* and Defoliart *et al.*, 1972). Isolates of Bunyamwera group virus have also been reported in other parts of Wisconsin (Anslow *et al.*, 1969). Activity of La Crosse virus in Wisconsin chipmunks was noted as far east as Dane County (Thompson, pers. comm.), about 100 miles from the Parkside study area.

Data on Parkside mammal population density and dynamics is presented in an accompanying paper (Amin, p. 311 these Transactions). The appropriate vectors of these viruses are also abundant

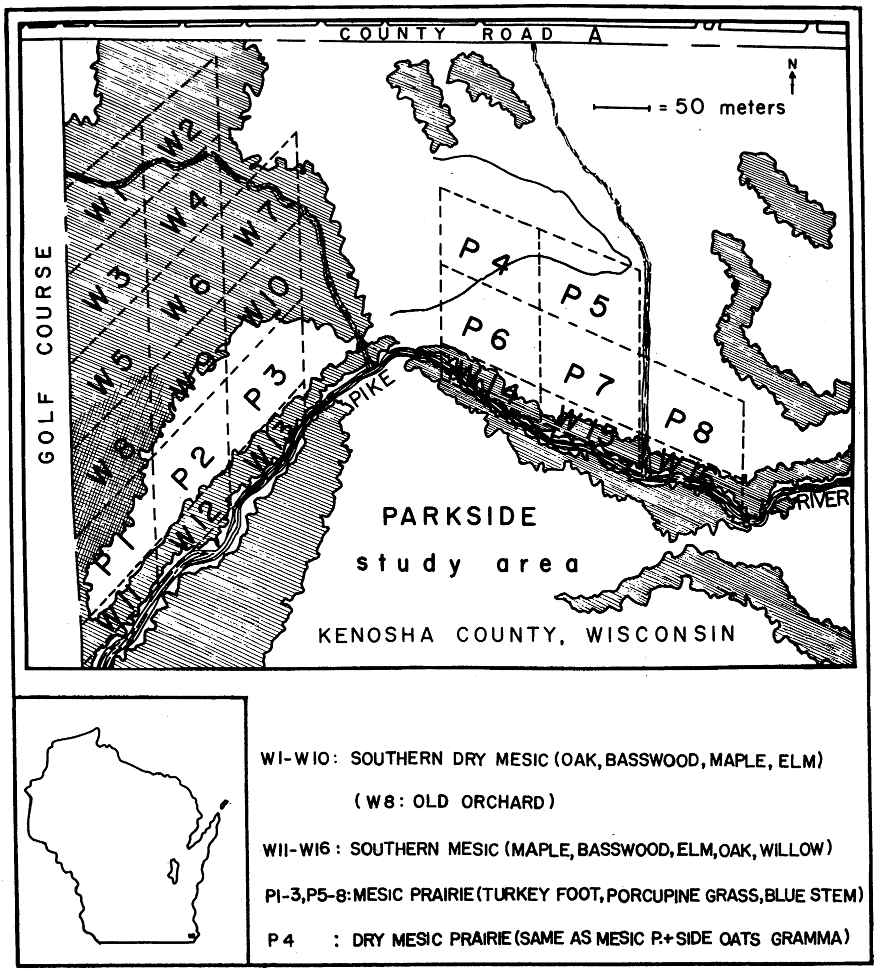

FIGURE 1. The Southeastern Wisconsin study area at Parkside.

in southeastern Wisconsin as well as in the southwestern portion of the state where endemic virus activity has been detected. Table 2 summarizes data for six *Aedes* mosquito species collected during July, 1972 in the Parkside study area as well as in nearby localities of similar botanic composition. More detailed information on Parkside mosquitoes will be published elsewhere. The absence of neutralizing antibodies can thus only be accounted for by a comparative lack of La Crosse virus activity in the area. The phytogeographic nature of southeastern Wisconsin might represent an important factor supporting this hypothesis. The deciduous wooded areas where

TABLE 2. *AEDES* COLLECTIONS FROM PARKSIDE STUDY AREA AND NEARBY LOCATIONS, JULY 1972

Aedes spp.	Parkside		Biting data in nearby wood lots		
	Trap. collect.	Biting collect.	E & Hy 31	Pet. Springs Park	North Racine
A. communis group	73 (7.5%)	59 (12.1%)	8 (10.2%)	15 (14.3%)	10 (3.2%)
A. dorsalis	0 (0.0%)	0 (0.0%)	6 (7.7%)	0 (0.0%)	0 (0.0%)
A. stimulans	5 (0.5%)	68 (14.0%)	2 (2.6%)	6 (5.7%)	95 (30.2%)
A. triseriatus	12 (1.2%)	32 (6.6%)	10 (12.9%)	6 (5.7%)	1 (0.3%)
A. trivittatus	150 (15.3%)	143 (29.4%)	15 (19.2%)	31 (29.5%)	69 (21.9%)
A. vexans	738 (75.5%)	184 (37.9%)	37 (47.4%)	47 (44.8%)	140 (44.4%)
Total	978 (100.0%)	486 (100.0%)	78 (100.0%)	105 (100.0%)	315 (100.0%)
Trap or aspiration hrs.	96[2]	3	1	1:30	data not available

[1]More *A. triseriatus* were aspirated in north Racine in other, not fully recorded, collections during July, 1972.
[2]Three CDC light traps and 3 dry ice (CO_2) traps were operated for four 24 hour periods.

A. triseriatus breeds (in basal tree holes) and chipmunks and gray squirrels abound, in the southeastern corner of the state, are usually represented by small isolated wood lots. This situation could present a kind of natural barrier to the spread of these viruses.

The absence of antibodies to BUN and other California group (TVT and JC) viruses in the sera of these chipmunks and squirrels is not as indicative of the lack of activity in the area, because these animals have not been established as good hosts for replication of these other viruses and for antibody production, as they have been with La Crosse.

POWASSAN VIRUS

No reportable HI reactions with Powassan antigen were found in the routinely collected samples in this study. One low titer reaction (1:10 only) was seen with the serum of a raccoon which had been road-killed, but is not considered as significant because of the likely presence of non-specific inhibitors. Serological evidence demonstrated antibody reaction against Powassan virus in raccoons, foxes, and humans in the state of New York (Whitney, 1963). Natural foci of infection appear to exist in Connecticut and South Dakota in *Ixodes spinipalpis* taken from *Peromyscus* mice as well as in Colorado in *Dermacentor andersoni* (Thomas *et al.*, 1960 in McLean and Larke, 1963).

WESTERN EQUINE ENCEPHALITIS

The one low level HI reaction with the antigen for WEE virus with the serum from a gray squirrel (0.7 Kg. male) indicates possible presence in other animals or birds in this area. Cases of WEE have been occurring each year in Wisconsin horses. A few human cases have also been diagnosed during the past five years; it is likely that other mild cases were missed (Thompson, 1971). *Culex tarsalis,* a common vector of WEE collected only occasionally in Wisconsin, was not obtained in this study area. *Aedes vexans,* the most abundant mosquito in southeastern Wisconsin (Table 2) and elsewhere in the state, has also been reported as a natural vector of WEE virus (Miles, 1960). To date, no WEE virus isolates have been obtained from mosquitoes in Wisconsin. Infections in humans and horses are usually considered as dead-end infections because of relatively low and transient viremias.

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DISTRIBUTION AND ECOLOGICAL OBSERVATIONS OF WILD MAMMALS IN SOUTHEASTERN WISCONSIN

Omar M. Amin
University Wisconsin—Parkside

ABSTRACT

Seventeen species of small and medium, wild mammals were trapped during the 1972 season as well as during a pilot study (fall 1971) in two ecologically distinct habitats (deciduous woods and prairies) in the Parkside study area, Kenosha County, southeastern Wisconsin. Seasonal and spatial distribution, population dynamics and other ecological information are discussed for the more commonly encountered mammals; i.e., chipmunks, meadow jumping mice, gray squirrels, opossums, white footed mice, and raccoons. Activity usually increased from low in the spring to a peak in the summer and declined by October. Activity of gray squirrels was relatively higher in the spring with a peak in August. Chipmunks experienced a lull in activity during August and the activity peak occurred during September. Summer breeding activity in chipmunks was noted. Variations in population densities of the meadow jumping mice from year to year were observed. The occurrence of at least a second breeding season in these mice is suggested. Female raccoons that failed to conceive during the regular breeding season can apparently mate again and conceive during May or June. Additional notes on breeding and activity periods, preferred habitats, trap preferences, travelled distances, measurements and weights, and recapture data are also included.

INTRODUCTION

A survey of host-ectoparasite-pathogen systems was undertaken in a study area in southeastern Wisconsin between April and October, 1972, after a pilot study in fall 1971. Studies of arboviral antibodies and ectoparasitic arthropods (including mosquitoes) are reported by Amin and Thompson (preceding paper p. 303). The following data are concerned with the seasonal activity patterns, distribution, population dynamics and other ecological observations on some of the 17 mammal species captured.

MATERIALS AND METHODS

The Study Areas. The Parkside study area has been described by Amin and Thompson. The most prevalent ground layer species of plants in the southern mesic woods are *Osmorthiza claytoni,* of plants in the southern mesic woods are *Osmorhiza claytoni,* and *Smilacina racemosa.* The most prevalent ground layer species of the southern dry mesic woods are *S. racemosa, Amphicarpa bracteata, O. claytoni,* and *Desmodium glutinosum.*

Considerably more area of similar prairies and wood lots (wet and dry mesic and mesic) lie directly south (across the Pike River) and east of this area. County Road A runs east-west directly north of it across from which similar habitats as well as farm lands are located. A golf course partially separates the western boundaries of the study area from the larger deciduous forest (southern mesic) of the Petrifying Springs Park.

Animal capture and examination: The methods for capture of the animals and the records made in classification of them have been described in Amin and Thompson. Details as to the dates of capture, recapture, and descriptions of the animals are given in this paper. Temperature, precipitation, and relative humidity were regularly recorded.

RESULTS AND DISCUSSION

Seventeen mammal species were captured, 2 of which were obtained only during the pilot study; i.e., Prairie vole *(Microtus ochrogaster)* and short tail shrew *(Blarina brevicauda)*. These data are shown by season in Table 1. During the 1972 season, a total of 356 animals were initially captured of which 158 were recaptured 358 times (Table 3).

Eastern Chipmunk, *Tamias striatus ohionensis* Moulthrop

The Eastern Chipmunk was the most commonly encountered mammal. Twenty two specimens (and 16 recaptures) were recorded during the pilot study. During the 1972 season the total number of trap entries exceeded half that of all other mammals combined (Table 1). Of the 160 initial captures, 35 (22%; 16 males and 19 females) were juveniles which entered the traps between June and October.

Animals weighing 50–74 g measured 200–260 mm (230)[1] in total length and 70–100 mm (87) in tail length (N=21). Animals weighing 75–99 g measured 215–280 mm (249) in total length and 80–110 mm (94) in tail length (N=40). Animals weighing 100 to

[1] Figures in parenthesis represent means.

TABLE 1. MAMMALS CAPTURED IN THE PARKSIDE STUDY AREA (KENOSHA COUNTY) DURING 1972

	Trapping periods[1]							Total 37
	April 3	May 5	June 6	July 5	Aug. 6	Sept. 8	Oct. 4	
Eastern Chipmunk	1,1[2]	27,4	42,33	33,36	24,51	30,103	3,19	160,247 (407)[3]
Meadow Jumping Mouse	------	1,0	14,0	27,4	13,4	17,4	1,3	73,15 (88)
Eastern Gray Squirrel	12,0	6,9	5,15	5,15	5,21	7,4	2,4	42,68 (110)
Opossum	2,0	3,0	2,4	3,5	2,3	8,3	4,1	24,16 (40)
White-footed Mouse	1,0	1,0	2,0	4,0	3,0	4,5	5,1	20,6 (26)
Raccoon	1,0	4,0	3,1	4,0	2,5	0,1	------	14,7 (21)
Cottontail Rabbit	------	------	1,0	2,0	------	3,0	1,0	7,0 (7)
Striped Ground Squirrel	------	------	------	------	2,0	3,0	0,1	5,1 (6)
Long-tailed Weasel	1,0	------	------	------	1,0	1,0	0,1	3,1 (4)
Eastern Fox Squirrel	------	------	------	1,1	1,0	------	------	2,1 (3)
Meadow Vole	------	------	------	2,0	------	------	------	2,0 (2)
Franklin's Ground Squirrel	------	------	------	------	------	1,0	------	1,0 (1)
Norway Rat	------	------	------	------	------	1,0	------	1,0 (1)
Striped Skunk	------	------	------	1,0	------	------	------	1,0 (1)
Southern Woodchuck	------	1,0	------	------	------	------	------	1,0 (1)
Total	18,1	43,13	69,53	82,61	53,84	75,120	16,30	356,362 (718)

[1] 24 hrs.
[2] No. of initial captures, no. of recaptures (trap entries) of recaptured animals.
[3] Total no. of trap entries.

130 g measured 230–300 mm (263) in total length and 75–115 mm (96) in tail length (N=82). Adult chipmunks of Wisconsin were reported by Jackson (1961) to reach 115 g in weight and a maximum of 265 mm in total length and 100 mm in tail length.

Sex ratio of all captures was equal. Chipmunks were almost exclusively active during daytime hours (especially in the morning and the late afternoon) in the deciduous woods. They entered trap size 1 almost as often as trap size 2 but rarely entered trap size 3A (Table 2). Chipmunks had the highest number of recaptures with 2 specimens recaptured 9 times (bait bias might be involved) and with a maximum distance recorded of 475 meters travelled by a male during 1972 (Table 3). Burt (1969) mentioned a home range of "seldom more than one hundred yards in greatest diameter," Jackson (1961) indicated a "maximum radius of about two hundred feet from homesite."

The following information suggests that male chipmunks might be relatively more active than females as judged by the frequency of trap entries and of recapture away from homesite (footnote, Table 3). Of the 160 initially captured chipmunks, 92 (46 males and 46 females) were recaptured 1–9 times. The average number of trap entries was 3.3 for males and 2.7 for females. The majority of males and females (60%) were consistently recaptured within their homesite (same trapping station). However, 25% of the males and 35% of the females were recaptured within 75–100 meters from their homesite. The remainder, 15% and 5% of the

TABLE 2. SEX RATIO, ACTIVITY HOURS, HABITAT PREFERENCE, AND TRAP SIZE PREFERENCE OF PARKSIDE MAMMALS, 1972

Mammal species	Number		Sex ratio[2] M:F	Percent		Percent enter. traps size[3,6]		
	Capt.[1] (A)	Total (B)		active day hours[3]	capt. in woods[3]	1	2	3A
Eastern Chipmunk	160	407	1:1	98[4]	98[5]	47	52	1
Meadow Jumping Mouse	73	88	1:1.3	15	15	69	31	0
Eastern Gray Squirrel	42	110	1:0.8	98[4]	100	17	18	65
Opossum	24	40	1:1.7	0	100	5	37	58
White-footed Mouse	20	26	1:0.7	0	92	100	0	0
Raccoon	14	21	1:2.2	0	93	0	0	100
Cottontail Rabbit	7	7	1:3.0	0	86	10	30	60
Striped Ground Squirrel	5	6	1:0.2	100	0	83	17	0
Long-tailed Weasel	3	4	1:2	0	75	0	100	0
Eastern Fox Squirrel	2	3	0:2	100	100	33	0	67
Meadow Vole	2	2	1:1	0	0	100	0	0
Franklin's Ground Squirrel	1	1	0:1	100	0	0	0	100
Norway Rat	1	1	0:1	0	100	100	0	0
Striped Skunk	1	1	-	0	0	0	0	100
Southern Woodchuck	1	1	-	100	100	0	0	100

[1]From last column, Table 1.
[2]Based on column (A).
[3]Based on column (B); the remainder were active at night (recovered at dawn) or was captured in prairie.
[4]The remaining 2% appear to have been active shortly before or during sunset and thus mixed with the night catch.
[5]Three of the 6 chipmunks reported in the prairie were yearlings captured during June-August.
[6]Trap sizes: 1 = 45x13x13 cm 2 = 60x18x18 cm 3 = 105x28x32 cm.

males and females were recaptured as far as 475 and 425 meters from the homesite, respectively. The average distance travelled was, however, about 34 meters by both sexes.

Population density in Parkside deciduous woods was estimated at 11 chipmunks per acre. This figure is relatively higher than the average of 6–8 per acre, but lower than the maximum of 20 per acre found by Jackson (1961) elsewhere in Wisconsin.

Chipmunks, as well as other mammals, were blood sampled by heart puncture for the arboviral antibody survey. Data regarding the effect of such sampling procedure on the weight changes in the mammal species were available only for chipmunks because of the adequate number of recaptures 1–2 days following initial blood sampling during the first day of the biweekly trapping sequence. Animals initially weighing 85–99 g (92.5) (N=11) from which 0.1–1.5 ml (0.83) of blood was withdrawn by heart puncture lost an average of 1.9 g (—13 to +11) in body weight 1–2 days later. Animals weighing 100–122 g (114) (N=15) from which 0.2–1.4 ml (0.59) of blood was withdrawn lost an average of 3.7 g (—13 to +8) in body weight. Weight loss in older chipmunks was about twice that in younger animals despite the smaller average volume of blood withdrawn from the older group. Apparently younger chipmunks are less susceptible to weight loss, or more efficient in recovery.

Only one specimen was captured during April (Table 1). Chipmunks were, however, observed sporadically in the study area and in nearby localities at least during most of March. Their activity index increased sharply between April and May following the termination of the last freezing temperatures in the latter part of April. Activity continued to increase reaching two peaks in July and September. Dunford (1972) observed the same phenomenon in New York and was unable to relate it to unfavorable high temperatures, breeding activity, or food shortage. A dramatic decline

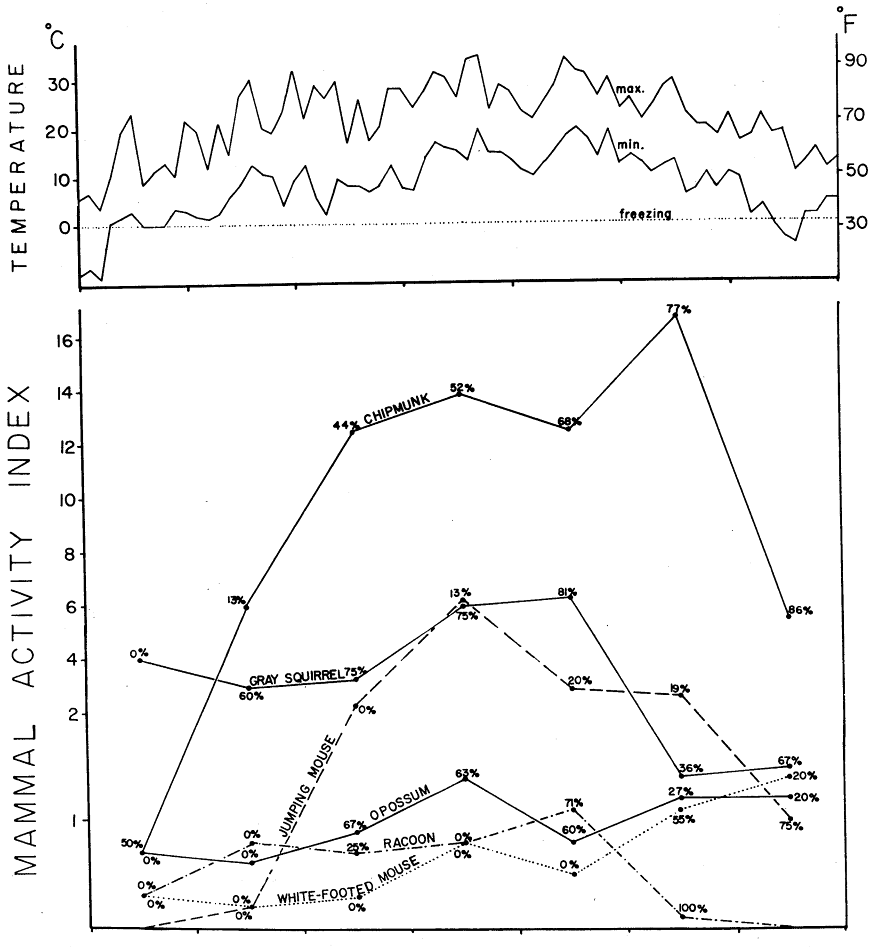

FIGURE 1. Activity (total trap entries) of 6 mammal species captured in the Parkside study area correlated with seasonal temperatures, 1972.
Percentages in the lower figure represent the proportion of recaptures in the total number of trap entries of each mammal species during the corresponding month.

in activity occurred in October following near and below freezing temperatures in that month (Fig. 1). Chipmunks were seldom seen after October. The percentage of recaptures on the activity curve increased progressively from 13% in May to 86% in October. Between November and March the eastern chipmunk was reported to be inactive-dormant but not a regular hibernator (Jackson, 1961).

Highest activity in terms of total number of trap entries was noted near streams bordered by hill slopes; i.e., in W 1, W 2, and W 12 (Fig. 1 of Amin and Thompson). This might have resulted partially from proximity of nesting sites. Activity was second highest in W 6-W 11, W 13, but minimal in the center of the wooded plateau farther away from the stream (W 3-5) as well as in the relatively isolated W 14-W 16.

Data on seasonal weight changes show that spring mating activity appeared to have occurred at least during the latter half of March (Fig. 2C). Supporting data include the capture of pregnant female no. 99 on 5 May which was lactating on 27 May and the capture of the earliest and youngest female no. 64 on 9 June. According to Jackson (1961), the young do not leave the den before 40 days after birth following a gestation period of about 31 days. By using data from Allen (1938), male no. 104 which weighed 80 g on 25 June (Fig. 2C) was estimated to have been about 2 months old; i.e., born during the last week of April. Similarly, male no. 208 which weighed 78 g on 19 August was estimated to be about 2 months old. The above data show that births resulting from spring breeding activity continued for at least 2 months between late April and late June, 1972. The same data (Fig. 2C) also show that summer breeding activity does take place. Jackson (1961) indicated that summer mating in Wisconsin occurs between the end of June and the end of July. My data for pregnant female no. 28 captured on 21 July and lactating females nos. 28, 227, and 247 captured on 5 August and 2 and 16 September, respectively, suggest that summer mating started during the second half of June and continued until early August. Similar observations were made by Allen (1938) in New York.

Fig. 2C also indicates a relatively fast rate of growth in juveniles between June and early August. Weight increase slowed down considerably between early and mid-August and mid-September. This slow down might be related to the late summer lull in activity referred to above. During the remainder of September and October faster weight increases in the young resumed. Chipmunks over one year of age did not seem to experience such dramatic weight changes. Weights of breeding females, nos. 99 and 28 (Fig. 2C), represented the expected changes resulting from pregnancy

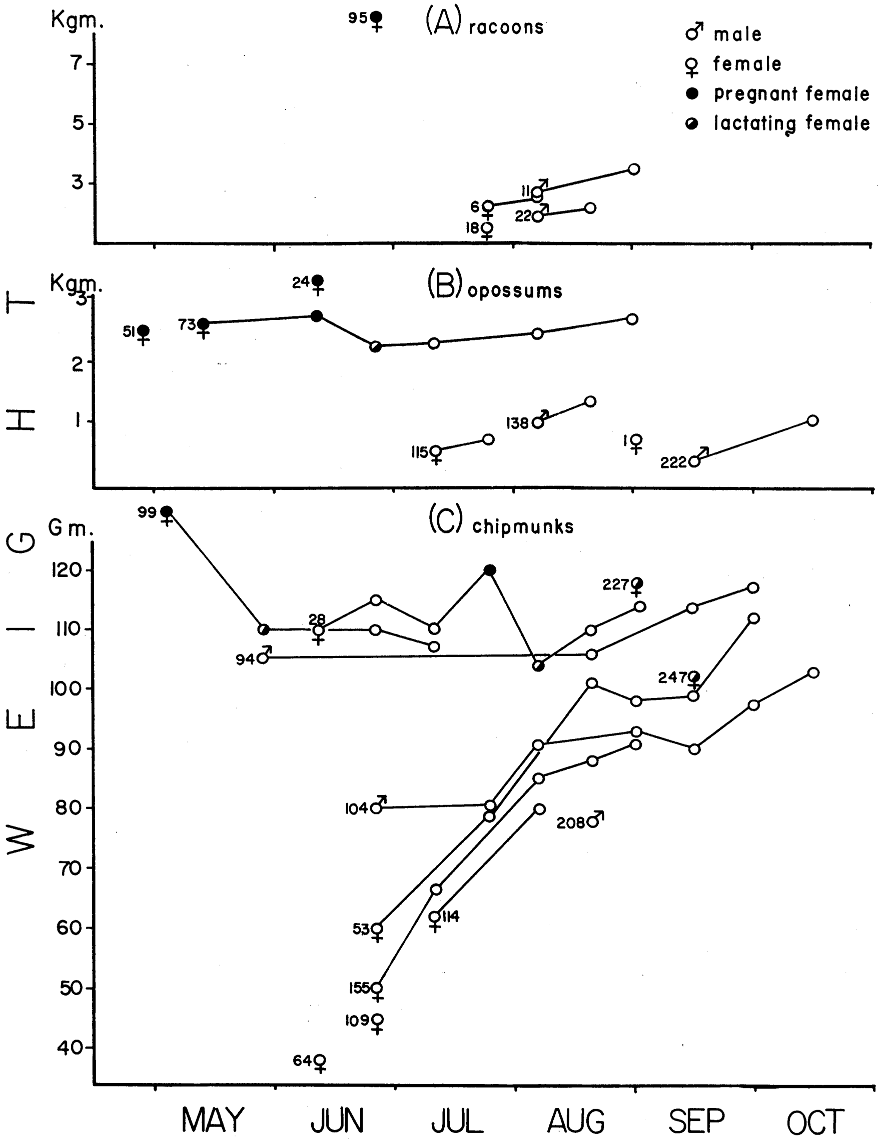

Figure 2. Seasonal weight changes of raccoons, opossums, and chipmunks.

and birth. Weights of breeding males, e.g., no. 94, show a moderate fall increase. The increase in weight in all above categories might be partially related to anticipated overwintering. Forbes (1966) noted that fall weight increases in some Minnesota chipmunks corresponded to accumulation of fat in relation to hibernation.

TABLE 3. SUMMARY OF RECAPTURE DATA OF THE 9 MAMMALS RECAPTURED DURING 1972 IN THE PARKSIDE STUDY AREA

Mammal species	Number of			Number of recaptures (maximum distance travelled, in meters)[1]								
	Initial captures	Recapt. animals	Total recapt.	1	2	3	4	5	6	7	8	9
Eastern Chipmunk	160	92	242	32 (100)	26 (475)	12 (100)	6 (300)	8 (375)	3 (000)	2 (150)	1 (000)	2 (100)
Meadow Jumping Mouse	73	14	15	13 (100)	1 (100)							
Eastern Gray Squirrel	42	33	69	21 (350)	3 (425)	3 (125)	3 (350)		2 (400)			1 (150)
Opossum	24	7	16	4 (200)	2 (250)						1 (450)	
White-footed Mouse	20	4	6	2 (175)	2 (000)							
Raccoon	14	5	7	4 (200)		1 (300)						
Striped Ground Squirrel	5	1	1	1 (100)								
Long-tailed Weasel	3	1	1	1 (125)								
Eastern Fox Squirrel	2	1	1	1 (100)								
Total	343	158	358									

[1]Maximum distance travelled = distance from a recapture site to a homesite (where the animal was most frequently captured) measured in a straight line.

Meadow Jumping Mouse, *Zapus hudsonius intermedius* Krutzsch

The jumping mouse had the second highest initial capture count (Table 1). The fact that none was captured during the pilot study (Sept., Oct. 1971), in contrast to 25 trap entries during September and October, 1972 in the same area might be explained by variation in population density from year to year. Jackson (1961) indicated that peaks of abundance of *Z. hudsonius* "do not seem to occur at the same time as peaks in other species." Supporting evidence from this study includes the fact that 15 meadow voles *(Microtus pennsylvanicus)* and no jumping mice were captured during the pilot study, whereas only 2 meadow voles and 73 jumping mice were captured during the 1972 trapping season. Similar associations between the above two mammals were reported in Michigan by Blair (1940).

Animals weighing 10 to 19 g measured 180–235 mm (206) in total length and 105–140 mm (124) in tail length (N=50). Animals weighing 20–25 g measured 200–240 mm (217) in total length and 125–145 mm (131 mm) in tail length (N=25). Adult jumping mice of Wisconsin were reported by Jackson (1961) to reach a maximum of only 227 mm in total length and 140 mm in tail length.

More females than males entered the traps (1.3:1) as shown in Table 2. However, Townsend (1935) and Blair (1940) reported 61% and 53% of 163 and 64 field collected mice, respectively, as males. The mice were usually active at night in open prairie situations. About 2/3 of the total captures occurred in traps of size 1 and the remaining in traps of size 2 (Table 2). No more than 2 recaptures were recorded of the same individual with a maximum distance recorded of 100 meters travelled by a female (Table 3).

Although only 14 jumping mice were recaptured, females appeared to be more active than males. None of 8 recaptured females was trapped in the same site twice with an average and maximum distance travelled of 85 and 100 meters, respectively. On the other hand, all but 2 of the 6 recaptured males were recaptured in the same site with an average and a maximum distance travelled of 25 and 75 meters, respectively.

No mice were captured in April and only one on 27 May. They were reported to emerge from hibernation in Wisconsin in late April to early May (Jackson, 1961). After the end of May, the activity index climbed rather rapidly to a peak in July. The steady decrease in activity during August and September continued to a minimum in October with 75% recaptures (Fig. 1). The above activity curve corresponded with the overall temperature changes during 1972. Entrance into hibernation presumably followed the first heavy frosts early in the fall.

The main breeding season apparently occurs in late May. Authors do not seem to agree whether *Z. hudsonius* has 1 or 2 other breeding seasons per year; see Jackson (1961) and Burt (1969) for lack of supporting information. Hamilton (1935) observed only one litter per year in New York. The following data indicate a second and possibly a third breeding season during July-August and during September, respectively, at least in southeastern Wisconsin. One pregnant and two lactating females were captured on 22 July; one pregnant and one lactating female were captured on 19 August; one lactating female was captured on 29 September. Blair (1940) indicated 2 peaks of breeding activity in Michigan, in the spring and in late summer.

Eastern Gray Squirrel, *Sciurus carolinensis hypophaeus* Merriam

The gray squirrel was the second most commonly encountered animal in terms of total number of trap entries (Table 1). Only one juvenile, weighing 0.162 Kg and measuring 370 mm in total length and 180 mm in tail length, was captured on 7 July. A considerably greater proportion of immatures was reported by Chapman (1938) in Ohio. Animals weighing 0.40 to 0.59 Kg measured 410–520 mm (480) in total length and 160–240 mm (215) in tail length (N=18). Animals weighing 0.60 to 0.80 Kg measured 460–560 mm (501) in total length and 190–260 mm (221) in tail length (N=29). Adult gray squirrels of Wisconsin were reported by Jackson (1961) to reach a maximum of only 540 mm in total length and 252 mm in tail length.

More males than females entered the traps (1:0.8). Sex ratio of captured squirrels appears to vary from year to year. Chapman (1938) reported 49, 60, and 39% males among 144, 55 and 89 gray squirrels trapped during 1935, 1936, and 1937, respectively, in Ohio. They were almost exclusively active during day hours and only in wooded situations. Most preferred entry in size 3A traps but 17% and 18% entered traps size 1 and 2, respectively (Table 2). Animals captured more than once did not show any pronounced consistency in trap size preference. Up to 9 recaptures of a female and a maximum distance of 425 meters travelled by a male (Table 3) were recorded. Jackson (1961) mentioned a usual home range of the gray squirrel "within one thousand feet of its nest", although it might travel distances of 4 miles or more in search of food.

Population density in Parkside deciduous woods was estimated at 2.4 gray squirrels per acre. Jackson (1961) found that one pair per acre is a common number in Wisconsin and that "populations of 20 or more to an acre of woodland may occur."

None of the 33 recaptured animals was exclusively trapped in the same site. Males appeared to be relatively more active than females. The 18 males travelled an average and a maximum distance of 112 and 425 meters. Corresponding figures in females were 70 and 325 (N=15). Similar observations were reported by Hungerford and Wilder (1941) in Connecticut. The average number of trap entries was 3 for recaptured males and females.

The activity curve started relatively high in April (Fig. 1) indicating a moderate activity prior to the initiation of trapping in that month. The slight decrease of activity in May corresponded with the spring canopy coverage and the possible relative obscurity of traps. Activity peaked in July and August but declined considerably in September. The slight increase during October indicates that activity did not cease after trapping was discontinued but probably continued at least during November. Personal observations substantiate the above information and also indicate that gray squirrels are also intermittently active throughout the winter, at least in southeastern Wisconsin.

Opossum *Didelphis marsupialis virginiana* Kerr

Three opossums were captured during the pilot study. During 1972, a total of 24 animals were captured (Table 1), of which 11 (45%; 4 males and 7 females) were juveniles, which entered the traps between July and October. Holmes and Sanderson (1965) reported that about 2/3 of over 400 trapped Illinois opossums were juveniles. Animals weighing 0.4 to 0.99 Kg measured 420–630 mm (506) in total length and 170–250 mm (206) in tail length (N=11). Animals weighing 1 to 1.9 Kg measured 600–700 mm (655) in total length and 210–300 mm (260) in tail length (N=4). Animals weighing 2–3 Kg measured 650–800 mm (738) in total length and 230–320 mm (280) in tail length (N=8). One pregnant female weighing 3.4 Kg which was captured on 9 June, measured 830 mm in total length and 300 mm in tail length.

More females than males entered the traps (1.7:1), as shown in Table 2. Jackson (1961), however, indicated that wild populations in Wisconsin have "normally about 20 percent more males than females." Similarly, Lay (1942) and Reynolds (1945) observed sex ratios of 1.33 males : 1 female in Texas and 1.22 males : 1 female in Missouri, respectively. Holmes and Sanderson (1965), however, reported an even sex ratio in Illinois with males being caught less frequently than females.

Opossums were active strictly at night in wooded habitats. McManus (1971) indicated that spring and summer nocturnal activity of captive opossums in New York peaked during midnight hours and markedly decreased toward dusk and dawn. However, in fall and winter, they were active at approximately the same level throughout the night. This hourly activity pattern was shown to be related to seasonal variation in ambient temperature. Over half of the captures were recorded in traps size 3A and most of the remainder in traps size 2 (Table 2). Up to 8 recaptures were recorded for one female with a maximum distance of 550 meters travelled by a female (Table 3). Jackson (1961) indicated that individuals "may wander a mile or more from the home site" in search of food, with a normal home range of 20–40 acres.

Females appeared to have been relatively more active than males with an average number of trap entries in recaptures of 2.4 and 1.3 respectively. The four females travelled an average and a maximum distance of 215 and 450 meters. Corresponding figures in males were 175 and 200 (N=3). The sample size of 7 recaptured animals was, however, too small to validate the above statement. Holmes and Sanderson (1965) indicated that adult males are much more mobile than adult females and juveniles.

Opossum activity gradually increased from low in April to a peak in July (corresponding with increased temperature), declined in August but retained a moderate level during September and October. The per cent recaptured in the latter 2 months was low because of the more frequent trap entries of juveniles. After October and during winter, opossums were occasionally seen wandering at night in and around the study area.

The recovery of pregnant females nos. 51, 73, and 24, during May and June and of juveniles between early July and September (Fig. 2B) indicated a breeding season between March and end of May and possibly early June.

White-footed Mouse *Peromyscus leucopus noveboracensis* (Fischer)

White-footed mice appear to have been more abundant in 1971 than in 1972. During September, October, 1971 17 specimens were trapped (with 2 recaptures), while during the whole 1972 season a total of 20 animals entered the traps (with 6 recaptures) (Table 1). Animals weighing 10 to 19.9 g measured 135–190 mm (158) in total length and 60–80 mm (70) in tail length (N=9). Animals weighing 20 to 26 g measured 145–190 mm (165) in total length and 65–80 mm (75) in tail length (N=10).

More males than females entered the traps (1:0.7); see Table 2. In Michigan and Connecticut, Nicholson (1941) and Hirth (1959) reported similar observations (68 and 58% males, respectively).

Nicholson (1941), however, reported more even sex ratios among litters and immatures. They were exclusively active at night, mostly in wooded areas (Table 2). Activity was reported to peak at and shortly after sunset in Ontario (Mann, 1954); near Madison (Emlen *et al.*, 1957); and in Connecticut (Hirth 1959), as well as shortly before sunrise near Madison (Emlen *et al.*, 1957). They were only captured in size 1 traps (Table 2). No more than 6 recaptures were recorded with a maximum distance of 175 meters travelled by a male (Table 3). The 2 recaptured females were each trapped twice in the same site. Nicholson (1941) and Hirth (1959) indicated greater travelling distances for males than for females in southern Michigan and in Connecticut, respectively. Jackson (1961) indicated a normal home range of about 0.25 acre.

After April, activity increased progressively during the trapping season to a peak in October. There was a slight decline only during August (Fig. 1). Burt (1969) mentioned a resting period (from breeding) in July or August. The consistent increase in activity after August indicated a marked activity at least during late fall and early winter in southeastern Wisconsin. Hirth (1959) suggested an inverse correlation between rainfall (when it occurred before midnight) and activity (judged by frequency of trapping success).

Breeding was reported to occur between March and October (Nicholson, 1941, Hirth, 1959, Jackson, 1961, and Burt, 1969) with 4 broods being raised between April and November (Jackson, 1961, and Burt, 1969). The recovery of pregnant females on 9 July, 19 August, 15 September, and 13 October suggest the presence of the 3rd and the 4th breeding seasons in southeastern Wisconsin.

Raccoon *Procyon lotor hirtus* Nelson and Goldman

Fourteen raccoons were captured of which 6 (43%; 2 males and 4 females) were juveniles, which entered the traps between July and September. Mech *et al.* (1968) indicated an even ratio of young to adults in Minnesota. Stuewer (1943) observed 65% juveniles in Michigan and Sonenshine and Winslow (1972) reported about 20 and 23% juveniles in two Virginia localities. Animals weighing 1.5 to 3.45 Kg measured 590–700 mm (630) in total length and 150–220 mm (180) in tail length (N=6). Animals weighing 3.5 to 5.49 Kg measured 750–880 mm (828) in total length and 250–290 mm (266) in tail length (N=5). Two animals weighing 5.5 and 7.2 Kg measured 830 and 970 mm in total length and 230 in tail length. One pregnant female weighing 8.5 Kg, which was captured on 23 June, measured 970 mm in total length and 330 mm in tail length. Adult raccoons of Wisconsin were reported by Jackson (1961) to reach a maximum of only 960 mm in total length and 275 mm in tail length.

More females than males entered the traps (2.2:1). Other "field" sex ratios showed variable bias toward males, e.g. Stuewer (1943) (1.08:1) and Sonenshine and Winslow (1972) (1.64:1). However, sex ratio in litters was observed to be 1 male:1.36 females in Michigan (Stuewer, 1943). Mech *et al.* (1968) observed an even sex ratio in yearlings and adults in Minnesota. Raccoons were exclusively active at night and mostly in wooded areas. All entered size 3A traps (Table 2). No more than 3 recaptures were recorded with a maximum distance recorded of 300 meters travelled by a male. Stuewer (1943) observed that males travel more extensively than females. Jackson (1961) indicated a normal home range of about 2 miles.

The activity of raccoons increased from low in April to a peak in August, declined considerably in September, and was not back to peak in October; a pattern corresponding closely with that of the prevailing temperatures.

Jackson (1961) and Burt (1969) referred to one mating season during late January and February with young being born in April and May after a gestation period of about 64 days. Juveniles nos. 6, 18, 11, and 22 (Fig. 2A) appear to be the products of such a breeding season. Juveniles nos. 6 and 18 were estimated to have been 13 and 11 weeks old (using Stuewer's, 1943 weight/age data) and to have been born in mid- or late April, respectively. The pregnant female (no. 95) which was captured on 23 June, however, did not fit this pattern. She must be considered as a female that did not conceive during the regular breeding season and that mated again sometime during May or June. Stuewer (1943) and Jackson (1961) also reported such cases. Births as late as August and September were reported in New England States and Indiana by Whitney (1931) and Lehman (1968), respectively. Dorney (1953) took 2 males weighing less than 4 pounds from Horicon Marsh, Wisconsin in November.

Cottontail Rabbit *Sylvilagus floridanus mearnsii* (J. A. Allen)

Seven cottontails weighing 0.9–1.2 Kg and measuring 420–470 mm (443) in total length and 40–70 mm (54) in tail length were captured.

Striped ground Squirrel *Citellus tridecemlineatus* (Mitchill)

Five squirrels weighing 120–155 g and measuring 260–290 mm (270) in total length and 90–100 mm (95) in tail length were captured.

Long-tailed Weasel *Mustella frenata noveboracensis* (Emmons)

Three weasals weighing 184–215 g and measuring 390–440 mm (407) in total length and 130–180 mm (157) in tail length were captured.

Eastern Fox Squirrel *Sciurus niger rufiventer* Geoffroy–Saint–Hilaire

Two animals weighing 0.55 and 0.80 Kg and measuring 460 and 580 mm in total length and 180 and 260 mm in tail length were captured. Adult Fox squirrels of Wisconsin were reported by Jackson (1961) to reach a maximum of only 565 mm in total length.

Meadow Vole *Microtus pennsylvanicus* (Ord)

Two specimens weighing 40 g each and measuring 145 and 160 mm in total length and 40 and 42 mm in tail length were captured during the 1972 season. This species was apparently more abundant during 1971; 15 specimens were captured during the pilot study (with one recapture).

Franklin's Ground Squirrel *Citellus franklinii* (Sabine)

One female weighing 300 g and measuring 360 mm in total length and 135 mm in tail length was captured.

Norway Rat *Rattus norvegicus* (Berkenhout)

One pregnant female weighing 230 g and measuring 370 mm in total length and 160 mm in tail length was captured on 30 September.

Striped Skunk *Mephitis mephitis hudsonica* Richardson

One skunk was captured on 21 July, 1972. Another one was trapped during the pilot study on 10 October, 1971 which was recaptured the following day.

Southern Woodchuck *Marmota monax monax* (Linnaeus)

One specimen weighing 4.1 Kg and measuring 710 mm in total length and 150 mm in tail length was captured on 28 May, 1972. Adult woodchucks of Wisconsin were reported by Jackson (1961) to reach a maximum of only 640 mm in total length.

Additional information on the above less abundant mammals is included in Tables 1–3.

ACKNOWLEDGEMENT

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SAMPLING AND ANALYSIS OF BOTTOM SEDIMENTS OF SOME WISCONSIN LAKES

Laverne C. Stricker
and
Robert N. Cheetham, Jr.
U.S.D.A. Soil Conservation Service—Madison

ABSTRACT

From 1971 to 1973, bottom sediment core samples were taken in nine Wisconsin lakes. The samples were first described in the field and then analyzed for physical characteristics, organic content, and phosphorus.

The watershed and lake characteristics of Big Spring Pond in Adams County and East Silver Lake, Monroe County, are discussed in detail.

INTRODUCTION

Bottom sediment samples were collected through the ice and from a boat with a core sampler developed at the University of Wisconsin Water Chemistry Laboratory. Nine lakes were sampled:

Big Spring Pond—Adams County
Little Green Lake—Green Lake County
Lilly Lake—Kenosha County
Angelo Pond—Monroe County
Perch Lake—Monroe County
East Silver Lake—Monroe County
Lake Leota—Rock County
Spauldings Pond—Rock County
Wautoma Pond—Waushara County

The samples were first described in the field and then analyzed for physical characteristics, organic content and inorganic phosphorus. Analyses were done according to Schulte and Olsen, 1970, procedures at the Soil and Plant Analysis Laboratory, Department of Soil Science, University of Wisconsin—Madison.

The studies consisted of evaluating watershed and lake characteristics. Based on these findings, recommendations are made for pond or lake improvement.

Two of the nine lakes were selected to emphasize the extreme variation of watershed and lake characteristics—Big Spring Pond, Adams County and East Silver Lake, Monroe County.

BIG SPRING POND

Watershed Information

Big Spring watershed is in New Haven Township, southeastern Adams County, Wisconsin, about eight miles NE of Wisconsin

Dells. The watershed has a drainage area of 1,677 acres, or 2.62 square miles. Big Spring Pond has a surface area of 7.3 acres. The Big Spring area is topographically mapped on the 15-minute Briggsville, Wisconsin, Quadrangle, 1958 edition, published by the United States Geological Survey. The contour interval is 20 feet. Agricultural Stabilization and Conservation Service (ASCS) contact aerial photographs, scale 1 inch equals 1,667 feet, AJA-1FF-96 of 7/15/65 and AJA-1FF-96 of 7/15/65 provide stereographic coverage.

Adams County has a humid continental climate with wide extremes of temperature. The coldest month is January with an average temperature of 17 F. July, the warmest month, has an average temperature of 73 F. The average rainfall is 31 inches and occurs mainly during the growing season of 130 to 140 days. The 1968 map *Soils of Wisconsin* by Hole, et al., indicates a general I 17 association of loams, clay loams, and sandy loams. Typical soil series are Manawa, Oshkosh, and Poygan. Adams County is a part of the Wisconsin Central Plain. Big Spring watershed is in that portion of the county invaded by the Pleistocene Green Bay ice lobe. Nearly horizontal quartz sandstones of Upper Cambrian Age are almost completely obscured by soils, alluvium and Pleistocene pitted outwash and till. To the east of Big Springs are glacial lacustrine deposits and to the west is the Johnstown Moraine of Wisconsin Age.

Land use was determined by field reconnaissance and aerial photographs.

	Acres
Cropland	965
Pasture	274
Woodland and Wildlife	356
Roads, Buildings, and Other	82
Big Spring Pond	7
Total	1,684

The Big Spring area was first settled in the fall of 1849 after treaty was made with the Menomonee Indians. By 1870 the area was in farmland and culturally accelerated erosion commenced.

With a modified Musgrave equation, a 635-acre sample was used to determine annual soil loss of cropland.

$$E=KCR \frac{(\%S)}{(10)}^{1.35} \frac{(LS)}{(72.6)}^{.35} ACPM$$

Where:
E is erosion in tons per acre
K is a function of soil type
R is rainfall erosiveness

S is slope
LS is length of slope
A is area in acres
C is rotation—crops
P is practice—as contour farming
M is management factor

Eight cooperators with the Adams County Soil and Water Conservation District own 1,231 watershed acres and six non-cooperators own the remaining 446 watershed acres. This is exclusive of the 7.3 acre lake.

Present average annual soil loss from cropland, as shown in Table 1, was estimated at 1.99 tons per acre; 0.12 tons per acre of soil loss from pasture; 0.12 tons of soil loss from woods and wildlife, and 4 tons per acre from roads and from dwelling and barnyard areas. Common cropland rotations are corn, oats, and two, three, or four years of hay. Streambank erosion and gully erosion, which are minor, were estimated after field inspection to cause 10% of the delivered upland sheet erosion to Big Spring Pond.

Converting to tons per year based on 100 lbs per cu ft yields an annual input of 1698.4 tons of sediment from erosion. The average soil loss from the drainage area is 1.01 tons per acre per year. The difference in the current estimated soil loss of 0.48 tons per acre per year and the determination of 1.01 tons per acre per year based on loss of pond capacity may be attributed to continuing and improved land treatment measures during the past 20 years.

TABLE 1. AVERAGE ANNUAL SEDIMENT YIELD BY SOURCES IN BIG SPRING WATERSHED (PRESENT CONDITIONS)

SHEET EROSION	Acres	Soil Loss (Tons/Ac)	Total (Tons)	
Cultivated Land	965	1.99	1,922	
Idle Land	--	--	--	
Pasture-Range	274	0.12	33	
Woodland-Wildlife	356	0.16	57	
Other (Roads—Buildings)	82	1.00	82	
			2,094	
			Delivery Ratio (%)	Tons Delivered
			35	733
GULLY EROSION STREAMBANK EROSION STREAMBED EROSION	Est. at 10% of delivered sheet erosion			73
			TOTAL	806 Tons

Pond Information

Big Spring Pond is described by Klick and Threinen, 1966, as a hard-water drainage lake with 7.3 surface acres. The water is light brown, alkaline, and has a low transparency. The fishery is largemouth bass, bluegills, pumpkinseed, and brook and brown trout. Game includes muskrat and ducks. Access, without parking facilities, is near the 11-foot head dam on a town road.

Based on interviews with several residents of Big Springs, it was determined that in 1951 maximum water depth of the lake was approximately 6 ft and average water depth 4 ft. Surface area then was 7.3 acres.

In 1971 surface area was unchanged, but maximum water depth (save at outlet) was 3 ft and average depth was 2 ft to the water-solids interface. The lake capacity or volume in 1951 was an estimated 29.2 acre feet and in 1971 only 14.6 acre feet. Therefore, in 20 years the loss of lake capacity averaged 0.78 acres feet per year.

In order to determine sediment accumulation in Big Spring Pond, visits were made to the area in January and June 1971. Water quality analyses and temperatures were taken in January. In June a core sample was obtained from a small pier west of the dam. Two attempts were made for core samples at the north end of the pond and at the outlet-dam area, with poor recovery because of rock and gravel fill near the dam. They were discarded.

The recovered sample was extruded from the plastic core barrel and representative upper, middle, and lower core segments were collected for analysis with results as given in Table 2.

The visual description of these sediments is as follows:

Sample	
0.8′	Watery collapsed—brown—black silt—no noticeable odor—modern plant fibres-roots.
1.0′	Uniform brown-black silty sand. No noticeable odor—some organic content.
0.2′	Silt, black, organic—fibres—shells.
0.5′	Silt, black, numerous fibres and shell fragments. Some fine sand.
0.2′	Silt, black, uniform, tr. sand.
0.1′	Silt, black, organic.
1.0′	Silt, black, fairly uniform with trace of clay and some find sand. Firm-poorly stratified. Some organic content.

Interpretation

The sediments in Big Spring Pond are mostly silt and organic as judged from the core samples take near the center of the lake.

TABLE 2. ANALYSES OF CORE SAMPLE FROM BIG SPRING POND

	Organic Matter	Inorg. P	Mechanical Analysis			Texture
			Sand	Silt	Clay	
Sample	%	ppm	%	%	%	
Top 0–1′	3.7	350	6	83	11	Silt
Mid. 2–2.5′	4.6	160	48	43	9	Loam
Bot. 2.7–3.7′	5.2	400	4	82	14	Silt

The surface of the sediments is mostly silt and has a very high inorganic phosphorus level. It is thought this layer of sediments was transported from the watershed through sheet erosion. A considerable amount of fertilizer is applied to the cropland in the watershed each year which may account for the high phosphorus level. Organic matter derived from plants and algae was not high at this location.

Below the top layer (2′–2.5′) there is a mostly sandy layer. The sand may have been transported simultaneously with the top silt but the sand, because of volume weight, settled out more rapidly. The sand probably originated from streambanks and road ditches and is not as fertile as the silt. The bottom layer is higher in organic matter and inorganic phosphorus. This was probably the original ground level before construction of the dam. The area was originally marsh and was inundated at time of dam construction.

EAST SILVER LAKE

Watershed Information

East Silver Lake is in Adrian Township on the Camp McCoy military reservation, Monroe County, Wisconsin. The lake is 7.5 miles SSW of Tomah. The watershed has a drainage area of 2,080 acres, or 3.25 square miles. The lake has a surface area of 6.5 acres. The East Silver Lake Area is topographically mapped on the 15-minute Tomah, Wisconsin Quadrangle, 1947 edition, published by the United States Geological Survey. The contour interval is 20 feet. Agricultural Stabilization and Conservation Service (ASCS) contact aerial photographs, scale 1 inch equals 1,667 feet, 55081 of 372–18 and 55081 of 372–19 of 10–7–72 provide stereographic coverage.

Monroe County has a humid continental climate with wide extremes of temperature. The coldest month is January with an average temperature of 14 F. July, the warmest month, has an average temperature of 73 F. The average rainfall is 30 inches and occurs mainly during the growing season of 135 to 145 days.

The 1968 map of *Soils of Wisconsin* by Hole, et al., indicates a general C-6 association of loamy sand and sand soil series such as Plainfield, Sparta, Gotham, and poorly drained undifferentiated alluvium; and, D1 steep rock land, loams, and silt loams whose typical soil series are Gale, Norden, Hixton, Fayette and Seaton. Monroe County is a part of the Western Uplands. East Silver Lake watershed is in the "Driftless" area of the county. East Silver Lake, fed by springs and seeps, drains westerly to the La Crosse River, a tributary to the Mississippi River.

Cambrian sandstones, shales, and siltstones crop out in the watershed but are somewhat obscured by loess, soils, alluvium, and colluvium. The sandstones outcrop near the upper end of the lake and are occasionally exposed by road-cuts. The Paleozoic formations appear almost horizontal except where slumped or settled. The higher bluffs have a thin Ordovician dolomite cap rock. Windrow Bluff, about three miles northeast of Silver Lake, is the type locality of the Windrow high level gravels of Cretaceous age.

Land use was determined by field reconnaissance and aerial photographs.

	Acres
Cropland	2.0
Pasture	—
Woodland and Wildlife	1967.5
Wetland	21.0
Roads, Ditches, Buildings, misc.	83.0
East Silver Lake	6.5
Total	2080

There are two landowners (Department of Defense and one farmer) who are cooperators with the Monroe County Soil and Water Conservation District. Several non-cooperators have parts of their farms in the upper reaches of the watershed.

Monroe County was created in 1854. Fruit and berry culture, dairying, and general farming were practiced. After 1890 the trend was toward dairying and general farming. Between 1908 and 1910 land was acquired by the Army for a military reservation known as Camp Robinson. After a varied history it was renamed Camp McCoy in 1926. From 1933–35 part of the camp was a CCC supply base of the U. S. Department of Agriculture.

Upland sheet erosion computations were made for two acres of hayland—on Boone Loamy sand. The land, classed as VIIs2, is on a 12% slope.

As shown in Table 3, the present average annual soil loss from cropped land is estimated at 1.6 tons per acre. Soil loss from wood-

TABLE 3. EAST SILVER LAKE: AVERAGE ANNUAL SEDIMENT LOAD BY SOURCES (PRESENT CONDITIONS)

SHEET EROSION	Acres	Soil Loss (Tons/Ac)	Total (Tons)
Cultivated Land	2.0	1.6	3.24
Idle Land	--	--	--
Pasture-Range	--	--	--
Woodland-Wildlife	1967.5	0.16	314.8
Roadside and Ditch	83.0	10.0	830.9
			1148
SHEET EROSION		**Delivery Rate (%)**	**Tons Delivered to Lake**
Total Tons		35	402
GULLY EROSION / STREAMBANK EROSION / STREAMBED EROSION	Est. at 10% delivered sheet erosion		40
		TOTAL	442 tons

land and wildlife is 0.16 tons per acre, and soil loss from roadside and ditch erosion is 10 tons per acre. Predicted current sediment yield from gross erosion delivered to East Silver Lake is 0.22 tons per acre per year. The most conspicuous sediment producing areas are the numerous roadbanks and ditches adjacent to and above the lake. Streambank and gully erosion are negligible to severe above the lake but were not studied separately in detail. Two gullies have fanned deltas into the lake. An estimate of 10% of the delivered upland sheet erosion was made for this type of sediment yield.

TABLE 4. ANALYSES OF THE 4 CORES FROM EAST SILVER LAKE

Core	Depths Analyzed	Sand %	Silt %	Organic Matter %	Inorg. P ppm
1	1′ 10″	99	0	1.28	2.8
	2′ 6″	50	30	12.82	15.0
	3′ 8″	99	0	1.09	5.0
2	— 7″	16	56	14.48	30.3
	— 10″	43	46	24.03	13.8
3	— 6″	17	54	13.22	13.8
	3′ 10″	98	0	0.36	0.9
4	1′ 14″	88	5	18.16	7.5
	3′ 0″	99	0	0.53	0.6

Lake Information

East Silver Lake is described by Klick, Gebken, and Threinen, 1969, as a hard-water drainage impoundment of 6.5 surface acres. The water is clear, medium hard, alkaline, and has a high transparency. Located entirely within Camp McCoy, the lake is managed by the federal government. Largemouth bass, northern pike, crappies, pumpkinseed, brook, brown, and rainbow trout compose the fishery. Access is by permit.

Sampling and Analyses

Four holes were made through the ice and cores collected as follows:

Core	Upstream From Dam	Thickness Of Ice	Bottom Depth	Profile	Sediment
1	125′	9″	7′	0 —1′10″ 1′10″—2′ 6″ 2′ 6″—3′ 8″	Sand Silty sand Sand
2	450′	11″	8:5″	0 — 7″ 7″— 10″	Sandy silt Silt and sand
3	450′	9″	8′	0 — 6″ 6″—3′10″	Sandy silt Sand
4	670′	8″	6′	0 —1′ 4″ 1′ 4″—3′ 0″	Sand, silty Sand

Interpretation

As shown in Table 4, the sediments in East Silver Lake are mostly sand and organic with some silt. Along the steep shoreline the sediments are mostly sandy on top. This is because of recent sliding of sand from the steep banks and delta deposits that have fanned out on the lake bottom. Further out, as in cores 2 and 3, the sediments are silty with higher organic content. At one time this layer was on the surface of the sediments but now has been covered by the sliding sand.

The sandy layer has encroached to a depth of around 6 ft in some areas. The deepest part of the lake appears to be around 9 ft. The silty organic layer is on the surface of the sediments toward the center of the lake; see core 2, Table 4. The silt in this layer probably originally eroded from agricultural land in the watershed. Most of this sedimentation occurred immediately after the lake was formed. Present-day erosion is carrying mostly sand particles and some silt.

The organic material in this layer is derived from decayed plant and animal remains within the lake. At times, aquatic plants and algae are abundant. After severe storms, branches and leaves may be transported to the lake.

The sandy layer is infertile; the silty organic layer is very fertile. Phosphorus levels mentioned here include only inorganic phosphorus. If organic phosphorus was included, much higher readings would be obtained for the organic material.

When the silty organic layer is in contact with water, the phosphorus may be continually recycled. This leads to an excessive nutrient supply in the waters of the lake and resultant aquatic plant problems.

PROPOSED IMPROVEMENT

To prevent aquatic plant and other problems, the sediment layer furnishing nutrients should be either covered or removed.

Big Spring Pond has a very fertile top sediment layer that should be removed. Improved oxygen condition in the pond would delay future buildup of this organic layer. Mechanical aeration is recommended. Releasing the outlet water from near the bottom of the pond would also delay organic sediment buildup. A new type of structure is recommended here. Nutrient contribution to the pond could be lessened through improved land treatment measures.

The sliding sand is covering the edges of East Silver Lake now. In time, this deposit could cover most of the lake bottom. Problems of lake shallowness could then occur. It would be best to attempt to stop the sliding sand where it is now and remove the silty organic layer from the center of the lake. This could be done by lake drawdown and allowing the layer to dry out, or by physical removal with a dredge or dragline. After removal of the silt organic layer, better nutrient discharge could be obtained by installing a bottom release outlet. The Soil Conservation Service has standard drawings for this type of outlet.

Land treatment measures to control erosion and sedimentation are needed above both bodies of water. Gully control structures and diversions should be planned for reducing the amount of sediment. The critical areas of roadside erosion should be resloped where possible, hand-mulched, limed, and seeded to vetch and grass.

Critical reaches of streambank erosion should be delineated and erosion control measures applied. The control may be simple or complex, depending on bank height, channel width, soil materials in bank profile, and presence or absence of bedrock in the channel. The majority of eroded material is derived from unstable banks, cut-banks, bank freeze and thaw, and bank-full waters. Riprap, deflectors, and bank sloping and seeding are most generally used. Occasionally debris basins or drop structures are needed in conjunction with other measures for streambank protection. While the acreage of cropland is very small, some additional land treatment measures are needed on the rather steep Class VII land, such as contouring. The most satisfactory treatment would be a changed land use to woodland and wildlife. Soil losses from wooded areas are being reduced by complete forest land management.

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STUDIES ON AQUATIC OLIGOCHAETA IN INLAND WATERS OF WISCONSIN

Richard P. Howmiller
University California—Santa Barbara

INTRODUCTION

Aquatic oligochaete worms, especially the Tubificidae, are common in the benthos of many lakes and rivers. In some aquatic environments, for example in polluted stretches of rivers and the profundal zone of many lakes, these organisms are often the most abundant of benthic macroinvertebrates.

Many of the aquatic oligochaetes occupy a niche similar to that of their terrestrial counterparts, ingesting and burrowing in the bottom sediments. Through these activities they may have profound effects upon the functioning of aquatic ecosystems. Under experimental conditions tubificids have been shown to promote the release of plant nutrients (Howmiller, unpublished) and pollutants (Jernelov 1970) from sediments, and to increase the rate of biochemical oxidation of sediments (Zvetlova 1972).

The worms are preyed upon by numerous invertebrate predators and by bottom-feeding fishes. Their importance as a food item of fishes is often underestimated because the worms are so rapidly digested that only unrecognizable fragments remain in stomach samples handled in the usual fashion. However, the fact that some tubificids serve as intermediate hosts of fish parasites (Calentine and Delong 1966, Calentine and Mackiewicz 1966) attests to their use as food by several fish species. The value of the worms as fish food is recognized by tropical fish fanciers who support a small industry supplying them with "tubifex worms"—the only direct economic importance of aquatic oligochaetes.

Pollution biologists have long associated an abundance of oligochaetes, coupled with a scarcity of other benthic invertebrates, with severe organic pollution. Thus one often sees the worms collectively referred to as "sludgeworms". In fact, only a few species of tubificids are tolerant of gross pollution. Thus, in recent years, attention has been focused on the possibility of a more sensitive index of environmental quality based on the relative abundance of species found to be intolerant, moderately tolerant, and very tolerant of organic enrichment. This interest has been a primary consideration in several studies of oligochaete species' distributions in waters of the Great Lakes. The worm fauna of the Great Lakes is now quite well known and it has become clear that polluted bays and harbors, and moderately enriched areas such as southern Lake Michigan, have characteristic species assemblages which are distinct from those of the open unpolluted areas of the lakes. The worm fauna of Great Lakes' waters bordering on Wisconsin has been studied by Hiltunen (1969a) in the Apostle Islands region of Lake Superior, Howmiller and Beeton (1970) in Green Bay, and Hiltunen (1967) and Howmiller (1972) in Lake Michigan proper. The fauna of these areas includes forty-one species of Oligochaeta (Howmiller and Beeton 1970).

Despite the importance of aquatic oligochaetes, and the frequency with which they are encountered by aquatic biologists, the fauna of most regions is poorly known. Though the aquatic biota of Wisconsin has probably been recorded more thoroughly than that of any other state, the literature contains only occasional records of oligochaetes at the species level. For many years, the records of *Sparganophilus eiseni* (= *S. tamesis*), *Lumbriculus limosa* (= *L. varigatus*), *Chaetogaster, Nais, Pristina, Limnodrilus claparedeianus,* and *Tubifex tubifex* from Lake Mendota (Muttkowski 1918) have constituted the most complete account of the aquatic Oligochaeta of Wisconsin. The purpose of the present communication is to record additional species from Wisconsin and to give an account of some ecological observations.

RECENT WISCONSIN RECORDS

Oligochaete species identified from my recent collections are listed in Table 1, in which localities are given as code letters. Explanation of the code letters, and locations of these lakes and rivers, are as follows:

Code	Lake or River	County
YL	Yellow Lake	Burnett
LK	Lake Kegonsa	Dane
LM	Lake Mendota	Dane
SP	Salmo Pond	Dane
TM	Theresa Marsh	Dodge
GL	Green Lake	Green Lake
LGL	Little Green Lake	Green Lake
GP	Grand Portage (Tank) Lake	Iron
KR	Kinnickinnic River	Milwaukee
MR	Milwaukee River	Milwaukee
RR	Root River	Milwaukee
CL	Clear Lake	Oneida
WR	Wisconsin River	Oneida
LP	Lake Pepin	Pepin
LMa	Lake Mallalieu	St. Croix

Code	Lake or River	County
DL	Devils Lake	Sauk
CrL	Crystal Lake	Vilas
TL	Trout Lake	Vilas
LD	Lake Delavan	Walworth
LG	Lake Geneva	Walworth
PL	Pleasant Lake	Walworth
LN	Lake Nagawicka	Waukesha
IF	(Illinois) Fox River	Waukesha
LW	Lake Winnebago	Winnebago
FR	Fox River	Winnebago

Nomenclature used in Table 1 follows that in the recent monograph of Brinkhurst and Jamieson (1971) except that *Limnodrilus spiralis* (Eisen) is here retained as a distinct species. *Limnodrilus spiralis* is separated from *L. hoffmeisteri* and other *Limnodrilus* species on the basis of differences in penis sheath morphology. The sheath of *L. spiralis* is, on the average, longer than that of *L. hoffmeisteri* and has its opening at the tip, surrounded by a flat plate with one edge upturned (Fig. 1a). The shorter sheath of *L. hoffmeisteri* is usually somewhat curved and is hooded with the opening at 90° to the shaft (Fig. 1b). Brinkhurst (Brinkhurst and Jamieson 1971) considers *L. spiralis* a synonym of *L. hoffmeisteri* and feels that a separate species should not be erected on the basis of the differences mentioned above unless the worms can be shown to be different in some other way. However, these differences are pronounced and, in my experience, intergrades are rare or nonexistent. It is difficult to be very positive on this last point since penis sheathes are often somewhat deformed when the animal is placed under a coverslip, especially in specimens where the sheath is just forming. Thus it is possible that a specimen with a sheath deformed in slide preparation could be mistaken for an intergrade, or vice versa. Differences in distribution of mature specimens of the two forms, in a lake in which both occur (Table 2), suggest that they are ecologically different in addition to being morphologically distinct.

Hiltunen (1967) found *L. spiralis* in Lake Michigan, but considered it a variant of *L. hoffmeisteri*. He has since recorded elsewhere[1] that *L. spiralis* is discontinuously widespread in the Great Lakes region, in mesotrophic and eutrophic habitats, and that specimens intermediate between it and typical *L. hoffmeisteri* are infrequently observed.

The question may merit further taxonomic investigation, but at present it seems appropriate to retain *L. spiralis* as a distinct species.

[1] Hiltunen, J. K. 1973. A Laboratory Guide; keys to the tubificid and naidid Oligochaeta of the Great Lakes region. Unpubl. ms. 24 pp.

TABLE 1. AQUATIC OLIGOCHAETA IDENTIFIED FROM RECENT COLLECTIONS AND LOCALITIES AT WHICH THEY WERE FOUND (FOR EXPLANATION OF CODE LETTERS SEE TEXT). SPECIES REPORTED BY MUTTKOWSKI (1918) FROM LAKE MENDOTA ARE MARKED WITH A SINGLE ASTERISK. ALL OTHERS ARE NEW RECORDS FOR INLAND WATERS OF WISCONSIN

Species	*Localities*
Lumbriculidae	
Lumbriculus variegatus (Verrill)*	SP, CrL
Naididae	
Arcteonais lomondi (Martin)	LMa, DL
Aulophorus vagus Leidy	TM
Dero digitata (Muller)	TM, LMa, DL, LN, FR
Haemonais waldvogeli Bretscher	TM
Nais elinguis (Muller)	TM
Nais simplex Piguet	LN
Ophidonais serpentina (Muller)	TM, LMa, DL, IFR
Stylaria fossularis Leidy	LGL, DL
Stylaria lacustris (Linnaeus)	TM, CL, LMa
Tubificidae	
Aulodrilus americanus Brinkhurst & Cook	YL
Aulodrilus limnobius Bretscher	YL, LMa, DL
Aulodrilus pigueti Kowalewski	YL, LMa, DL, LW
Aulodrilus pluriseta (Piguet)	DL
Branchiura sowerbyi Beddard	LP, LG
Ilyodrilus templetoni (Southern)	YL, LM, TM, LGL, GP, LMa, DL, CrL, TL, FR
Limnodrilus cervix Brinkhurst	LD, FR
Limnodrilus claparedeianus Ratzel*	LGL
Limnodrilus hoffmeisteri Claparede	YL, LK, LM, TM, GL, LGL, GP, KR, MR, RR, WR, LP, LMa, DL, CrL, TL, LD, LG, PL, IFR, LW, FR
Limnodrilus profundicola (Verrill)	GL
Limnodrilus spiralis (Eisen)**	LG
Limnodrilus udekemianus Claparede	RR, LMa, LG, IFR, FR
Peloscolex multisetosus multisetosus (Smith)	LMa, LG, FR
Peloscolex multisetosus longidentus Brinkhurst & Cook	KR
Potamothrix hammoniensis (Michaelsen)	LG
Potamothrix moldaviensis (Vejdovsky & Mrazek)	GLY, LMa, DL
Tubifex kessleri americanus Brinkhurst & Cook	GL
Tubifex tubifex (Muller)*	GL, KR, MR, WR, LMa, LG, FR

** see text

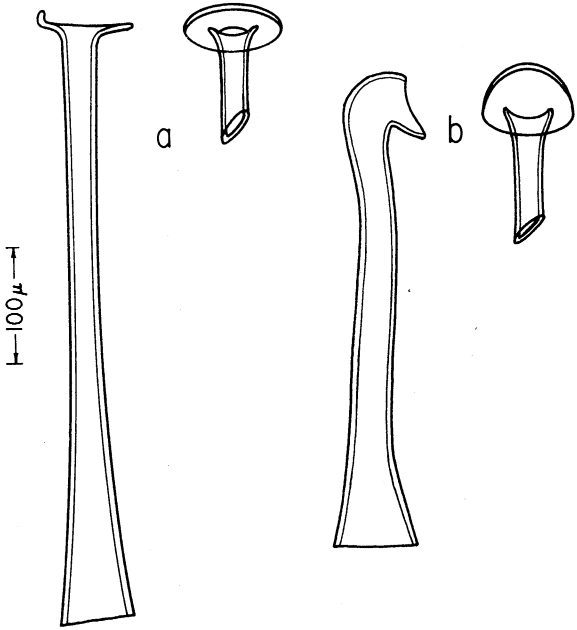

FIGURE 1. Illustrating differences in form of the penis sheath in (a) *Limnodrilus spiralis* and (b) *L. hoffmeisteri.* Drawn from Lake Geneva specimens.

The purpose of listing localities in Table 1 is not to suggest the existence of discrete species' distributions within the state but to indicate the degree of commonness or rarity of each of the species. In this regard it must be pointed out that there was some bias in sampling as most samples were taken in deeper waters free of macroscopic vegetation. The tubificids are thus more adequately represented than the naidids which prefer weedy littoral situations. However, many readers will recognize that the waters sampled represent a considerable variety of environmental conditions; from nearly oligotrophic Crystal Lake to the very eutrophic conditions of Lakes Winnebago and Delavan, and from the very shallow Theresa Marsh to Green Lake, the deepest lake in the state.

OLIGOCHAETA AND LAKE TYPES

Introduction

There is, of course, always an academic interest in defining the sorts of environments in which particular organisms are found. In recent decades there has been an increasing interest in asking

TABLE 2. ABUNDANCE OF TUBIFICID WORMS, AS INDIVIDUALS PER SQUARE METER, AT FIVE DEPTHS ALONG A TRANSECT IN LAKE GENEVA. ESTIMATES ARE BASED ON A SINGLE (15 X 15 CM) EKMAN GRAB SAMPLE AT EACH DEPTH EXCEPT FOR THE 27.5 M STATION WHERE FOUR SUCH SAMPLES WERE TAKEN. SEVERAL SAMPLES TAKEN FROM DEPTHS OF 36.5 AND 43.5 M CONTAINED NO MACROSCOPIC INVERTEBRATES

	Depth, meters				
	12.5	17.5	21.0	24.5	27.5
Branchiura sowerbyi	133				
Limnodrilus hoffmeisteri	222	174			
L. spiralis		290	1993	4098	22
L. udekemianus	44				
Potamothrix hammoniensis		58	87		11
Peloscolex multisetosus	178		87		
Tubifex tubifex		581			222
Undetermined immatures;					
with hair chaetae		2148	260	141	1566
without hair chaetae	133	3193	6240	2826	11
Total	710	6444	8667	7065	1832
Most probable no. species	5	4	4	2	3
Number Examined	16	111	100	100	165

this question in a slightly different way, viz; Which species of organisms are typically found in a particular type of environment? Adequate knowledge of this sort may allow us to use organisms as indicators of environmental quality. For example, changes in composition of the biota have provided useful indices for documenting the eutrophication of lakes (Brinkhurst 1969, Hooper 1969).

The bottom fauna of littoral areas has only limited value as an index of the trophic state of a lake, because littoral areas are strongly influenced by edaphic factors and often receive considerable inputs of allochthonous detritus. The profundal region, on the other hand, offers relative uniformity of environmental conditions. In many respects the conditions are related to the productivity of the overlying water. Chief among these are the quantity and quality of organic matter and the dissolved oxygen concentration (Jonasson 1972). Consequently, most attempts to correlate lake trophy and bottom fauna have been concerned with the profundal benthos.

Earlier work of this sort focused upon the larvae of chironomid midges (Thienemann 1922, Deevey 1941, Brundin 1958). Differences found, at the generic level, resulted in the formation of a "bottom faunistic lake type system" which seemed to have widespread applicability (Brundin 1958), although the relationship between productivity and bottom fauna was often complicated by morphometric influences (Brundin 1949).

Brinkhurst (1964) investigated the oligochaete fauna of a number of lakes in the English Lake District with this same question in mind. His results are a bit difficult for the reader to evaluate as species abundances are indicated merely as absent, present or abundant. Also, he presents no data to indicate how one might rank the lakes investigated using other criteria, saying only that they "have been held to represent a series according to the classical taxonomy of lakes". He concluded that his findings indicated several species to be common in a wide variety of lakes. Thus, while *Peloscolex ferox* seemed to be characteristic of less productive lakes and *Euilyodrilus (Potamothrix) hammoniensis* was increasingly common in more productive lakes, the data offered no more quantitative relationship between lake type and worm fauna composition.

In view of the previously mentioned studies on the Great Lakes, which have found species assemblages differing greatly under different environmental conditions, Brinkhurst's (1964) results seemed surprising. There seemed a possibility that relationships between worm faunal composition and lake type might be found elsewhere, where perhaps, there was a richer fauna to offer more ecologically specialized worm species. Thus the present study was undertaken.

Procedure

The twenty-six lakes chosen for investigation included all those studied by Lueschow and co-workers (1970). They measured a number of parameters indicative of trophic status of the lakes and calculated a "composite rating" which allowed a ranking of the lakes from most oligotrophic to most eutrophic. The other lakes included in the present investigation, with the exception of Devils Lake, were among those studied by Hilsenhoff and Narf (1968). Hilsenhoff and Narf measured various environmental factors thought to be important in regulating chironomid populations but did not rate the lakes as oligotrophic or eutrophic.

Environmental parameters measured during the investigations reported here included depth profiles of temperature and dissolved oxygen, transparency, color, conductivity, alkalinity, seston, and organic and carbonate content of sediments.[2] The data, particularly

[2] A detailed account of methods and limnological data comprises an August 1972 progress report to the Wisconsin Department of Natural Resources.

transparency, color, organic seston and total phosphorus values, were used to arrange the lakes in a trophic series (Fig. 2). Those lakes studied by Lueschow and co-workers (1970), are listed here in the same order as ranked by them on the basis of their "composite rating". Thus the data collected during the present investigation have essentially been used only to place the other lakes in their series. The order in Fig. 2 is thus meant to indicate trophic status, with the more oligotrophic lakes at the top of the list, and the most eutrophic at the bottom.

Samples for study of the oligochaete fauna were taken at some distance from shore, usually from a depth near maximum depth. In one instance (Lake Geneva, See Table 2) samples from a shallower depth, still well within the profundal zone, were substituted when deeper samples were found devoid of macroscopic organisms.

Four replicate samples were taken at the single sampling site in each lake using a 15 x 15 cm tall form Ekman grab. Samples were sieved immediately with a U.S. Std No. 30 screen (0.565 mm) and the residue from the screen preserved in 10% formalin. All organisms were picked from the preserved residue by hand, with the aid of low power magnification. Oligochaete worms were mounted whole on microscope slides with Turtox CMC or Amman's

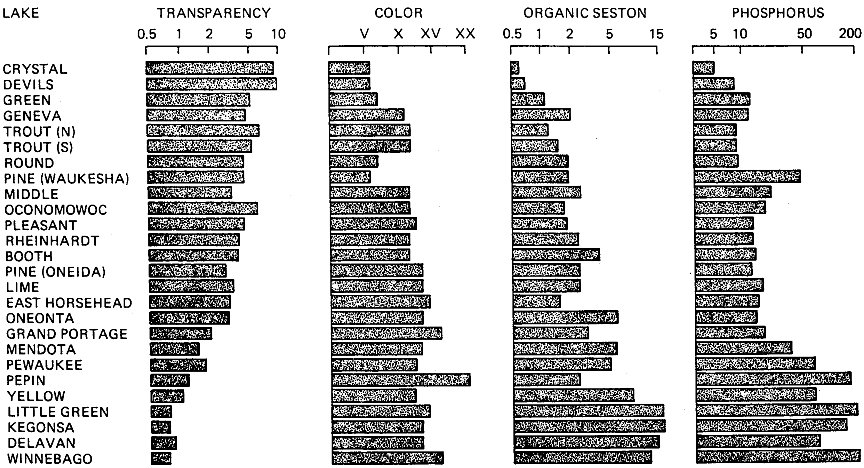

FIGURE 2. Illustrating values of some limnological parameters for twenty-six Wisconsin lakes. Transparency is in meters and was measured with a 20 cm all-white Secchi disc. Color was determined by comparison with a Forel–Ule scale. Organic seston data are given in mg/liter and were obtained by measuring loss on ignition of material on Whatman GF/C filters. Total phosphorus values are given in µg/liter; the samples were taken from a depth of 1.0 m and determinations made by the method of Schmid and Ambuhl (1965).

Lactophenol or a mixture of the two. They were examined after waiting several weeks for clearing of soft tissues.

Results and Discussion

Samples from the profundal of nine of the lakes (Round, Pine in Waukesha County, Middle, Oconomowoc, Booth, Lime, Oneonta, Pewaukee, and Delavan) contained no oligochaete worms. Note that while these lakes without worms fall in a range which may be described as mesotrophic to very eutrophic (Fig. 2), the six most oligotrophic lakes all contained oligochaetes in the profundal sediments.

All the oligochaetes found in these profundal samples belonged to the family Tubificidae. Table 3 lists the abundance of individual taxa for each of the seventeen lakes from which worms were collected. Absolute abundance is given as individuals per square meter, based on the mean of counts from the four Ekman grab samples. The standard error of the mean is also given in the table. Since in all cases the number of samples was four, the standard deviation is twice the standard error. The relative abundance of each taxon, as a percentage of the total number of tubificids, is also given in Table 3.

Before further reviewing Table 3, it should be pointed out that many common tubificids can be positively identified only when they are sexually mature and bearing sexual structures (e.g. genital chaetae or penis sheathes). Thus, in almost every case, it was impossible to identify many of the worms in the samples. These are listed as undetermined immatures and placed into two groups; those which possessed hair chaetae and those lacking hair chaetae. Knowing which species are present in the samples, from positive identifications of mature specimens, allows one to make a reasonable guess at the identity of immature specimens. Thus, in Table 3, I have listed probable abundance of *Limnodrilus hoffmeisteri;* this number including *L. hoffmeisteri* and a portion or all of the immature worms without hair chaetae. In cases where a portion of the immatures without hair chaetae could have belonged to another species (e.g. *L. profundicola* in Green Lake) the immatures were assigned to the two species on the basis of relative abundance of positively identified mature specimens. In the same manner, undetermined immature specimens without hair chaetae were included among probable numbers of *Ilyodrilus templetoni* or *Tubifex tubifex* depending on which was found as mature specimens in the particular lake. In one case (Lake Geneva) only a portion of the immatures with hairs was included among probable *Tubifex tubifex* because these could also have included immature *Potamothrix hammoniensis.*

This manipulation of data no doubt involves some error since it assumes that all species populations included some mature individuals. This is obviously not true, since many lakes contained immatures with or without hairs and no mature specimens which fit the category. Also, assignment of immatures to two species was done with the assumption that mature specimens constituted the same proportion of both populations. This assumption, too, is certainly in error to some extent. Unfortunately, there is no way to assess the magnitude of error introduced by these assumptions. As long as there is no way to reliably identify immature specimens and we lack life history information which might indicate the normal proportion of mature specimens under given environmental conditions, calculations of the sort described above will provide the only means of estimating the number of species in a lake and the relative abundance of each.

In these seventeen lakes, mean abundance of tubificids ranged from 11 individuals / m^2 in South Trout and Pine (Oneida County) to over 27000/m^2 in Green Lake (Table 3). The standard errors associated with these means are in many cases quite large, but small enough to leave no doubt that there are differences of several orders of magnitude in the abundance of tubificids in these lakes. It is clear that the four most oligotrophic lakes were the four in which oligochaetes were most abundant, but there was no consistent relationship between worm abundance and lake trophy when all seventeen lakes were considered (compare Fig. 2, Table 3).

It is apparent from Table 3 that *Limnodrilus hoffmeisteri* was, by far, the most common worm in the lakes. Of the seventeen lakes having worms in the profundal benthos, this species occurred in twelve (in thirteen if one includes *L. spiralis* in *L. hoffmeisteri*). It was clearly numerically dominant in most of these lakes (Table 3). This was not unexpected. *L. hoffmeisteri* is cosmopolitan and is generally the most common worm in any region (Brinkhurst and Jamieson 1971). It has been found to be the most abundant worm in studies of many types of environments, though in extreme cases this has often been associated with organic pollution (Brinkhurst 1969).

Ilyodrilus templetoni was the second most common and abundant species. It was represented by mature specimens in six lakes and probably occurred among the immature specimens of five other lakes (Table 3). In Crystal Lake and Lake Mendota, *I. templetoni* accounted for a considerable proportion of the worm fauna and this may have been true of several other lakes (South Trout, Rheinhardt, Pine in Oneida County, East Horsehead; Table 3).

TABLE 3. ABUNDANCE OF TUBIFICID WORMS IN THE PROFUNDAL SEDIMENTS OF SEVENTEEN WISCONSIN LAKES. THE UPPER PORTION OF THE TABLE GIVES ABUNDANCE IN INDIVIDUALS PER SQUARE METER, BASED ON THE MEAN OF COUNTS FROM FOUR 15 X 15 CM EKMAN GRAB SAMPLES, FOLLOWED BY THE STANDARD ERROR OF THE MEAN; AND, IN PARENTHESES, THE RELATIVE ABUNDANCE OF EACH TAXON, AS A PERCENTAGE OF TOTAL TUBIFICIDAE. THE LOWER PORTION OF THE TABLE LISTS PROBABLE NUMBERS OF *LIMNODRILUS HOFFMEISTERI*, *ILYODRILUS TEMPLETONI*, AND *TUBIFEX TUBIFEX* (SEE TEXT); THE MOST PROBABLE NUMBER OF SPECIES IN EACH COLLECTION, AND THE TOTAL NUMBER OF SPECIMENS EXAMINED

Taxon	Lake					
	Crystal	Devils	Green	Geneva	Trout (N)	Trout (S)
Aulodrilus pigueti						
Branchiura sowerbyi						
Ilyodrilus templetoni	478 ± 198 (21.3)				78 ± 21 (10.8)	11 ± 11 (100)
Limnodrilus claparedeianus						
L. hoffmeisteri	133 ± 41 (5.9)	44 ± 0 (3.6)	592 ± 318 (2.2)		178 ± 79 (24.6)	
L. profundicola			200 ± 139 (0.7)			
L. spiralis				22 ± 22 (1.2)		
Potamothrix hammoniensis				11 ± 11 (0.6)		
Tubifex tubifex			308 ± 133 (1.1)	222 ± 104 (12.2)		
Undetermined immatures; With hair chaetae	889 ± 107 (39.6)	111 ± 29 (9.2)	26092 ± 17168 (94.6)	1556 ± 294 (85.4)	11 ± 11 (1.5)	
Without hair chaetae	744 ± 250 (33.2)	1056 ± 100 (87.2)	369 ± 260 (1.3)	11 ± 11 (0.6)	456 ± 138 (63.0)	
Total Tubificidae	2244 ± 247	1211 ± 178	27564 ± 17645	1822 ± 424	722 ± 225	11 ± 11
"Probable *L. hoffmeisteri*"	39.1	90.8	3.5		87.6	
"Probable *I. templetoni*"	60.9	9.2			12.3	100
"Probable *T. tubifex*"			95.7	93.6		
Probable No. species	2	2	3	3	2	1
No. specimens examined	202	109	344	164	65	1

TABLE 3. (CONTINUED)

Taxon	Lake: Pleasant	Rheinhardt	Pine (Oneida)	E. Horsehead	Grand Portage	Mendota
Aulodrilus pigueti						
Branchiura sowerbyi						
Ilyodrilus templetoni					11 ± 11 (1.0)	133 ± 104 (27.2)
Limnodrilus claparedeianus						
L. hoffmeisteri	89 ± 48 (26.7)				367 ± 178 (34.4)	22 ± 22 (4.5)
L. profundicola						
L. spiralis						
Potamothrix hammoniensis						
Tubifex tubifex						
Undetermined immatures; With hair chaetae		67 ± 29 (100)	11 ± 11 (100)	22 ± 22 (100)		89 ± 36 (18.2)
Without hair chaetae	244 ± 38 (73.3)				689 ± 256 (64.6)	244 ± 82 (50.0)
Total Tubificidae	333 ± 56	67 ± 29	11 ± 11	22 ± 22	1067 ± 400	489 ± 180
"Probable *L. hoffmeisteri*"	100				99.0	54.5
"Probable *I. templetoni*"		100	100	100	1.0	45.4
"Probable *T. tubifex*"						
Probable No. species	1	1	1	1	2	2
No. specimens examined	30	6	1	1	96	44

TABLE 3. (CONTINUED)

Taxon	Lake				
	Pepin	Yellow	L. Green	Kegonsa	Winnebago
Aulodrilus pigueti					11 ± 11 (9.0)
Branchiura sowerbyi	122 ± 38 (14.8)				
Ilyodrilus templetoni			11 ± 11 (4.1)		
Limnodrilus claparedeianus			22 ± 13 (8.2)		
L. hoffmeisteri	89 ± 18 (10.8)	89 ± 18 (38.2)	100 ± 33 (37.4)	166 ± 21 (42.7)	67 ± 38 (54.9)
L. profundicola					
L. spiralis					
Potamothrix hammoniensis					
Tubifex tubifex					
Undetermined immatures; With hair chaetae					
Without hair chaetae	611 ± 93 (74.3)	144 ± 52 (61.8)	133 ± 18 (49.8)	222 ± 48 (57.1)	44 ± 18 (36.1)
Total Tubificidae	822 ± 116	233 ± 69	267 ± 31	389 ± 64	122 ± 64
"Probable *L. hoffmeisteri*"	85.1	100	78.3	100	91.0
"Probable *I. templetoni*"			4.1		
"Probable *T. tubifex*"					
Probable No. species	2	1	3	1	2
No. specimens examined	74	21	25	35	11

These findings contrast sharply with Brinkhurst's (1964) data from British Lakes which indicate that *I. templetoni* (as *Tubifex templetoni*) occurred in few lakes and was never abundant. Howmiller and Beeton (1970) found *I. templetoni* common in a portion of Green Bay but not so above the latitude of Sturgeon Bay or below Long Tail Point near the mouth of the Fox River. The species thus seems to be favored by moderate organic enrichment but intolerant of gross pollution.

Tubifex tubifex, third most common worm in these profundal samples, occurred in only two lakes but there comprised most of the worm fauna (Table 3). It may be of significance that the two lakes in which it occurred, Green and Geneva, are at the oligotrophic end of the series and are the deepest of these lakes. *Tubifex tubifex,* in puzzling contrast with its well-deserved reputation for tolerance of severe organic pollution in rivers and harbors, has frequently been reported as a relatively abundant species in the profundal of oligotrophic lakes. Brinkhurst (1964) reported that it alone occurred in material from high alpine lakes of Austria and this seems to be true as well of some oligotrophic sub-alpine lakes in the Sierra Nevada (Howmiller, unpublished). *Tubifex tubifex* occurs in the profundal benthos of the oligotrophic upper Great Lakes (Hiltunen 1967, Howmiller 1972) and in the less productive regions of the lower lakes (Brinkhurst and Jamieson 1971).

The three species just discussed, *L. hoffmeisteri, I. templetoni,* and *T. tubifex,* are the only common oligochaetes in the profundal region of these Wisconsin lakes. While six other species were found in the present series of samples, each occurred in only a single lake (Table 3). These lakes are thus at least as poor in species as those of the English Lake District investigated by Brinkhurst (1964). Of the twenty lakes which he sampled, four yielded no worms, seven contained only one species, six contained two species, and three had three species. Of the five species recorded from these English lakes; *Peloscolex ferox, Aulodrilus pluriseta, Tubifex tubifex, Ilyodrilus templetoni,* and *Limnodrilus hoffmeisteri,* only the latter occurred in more than half the lakes. *Aulodrilus pluriseta* and *T. tubifex* were found in only two lakes each.

The paucity of species in the profundal of inland lakes contrasts strongly with findings in bays, harbors, and littoral areas of the Great Lakes. For example, thirty species of Oligochaeta, including nineteen tubificids, have been reported from Green Bay. As pointed out by Dahl (1970), there are many possibilities for overland dispersal of oligochaetes. The occurrence of only a few species in the profundal of these Wisconsin lakes, considering their close proximity to the rich fauna of the Great Lakes, thus indicates that in terms of the requirements of oligochaete species, the profundal regions of inland lakes constitute a set of very similar environments. The corollary of this is that composition of the profundal oligochaete fauna has no index value for distinguishing between lakes within the range offered by the series investigated. There does seem some tendency for more oligotrophic lakes to be less likely to lack worms in profundal regions, and perhaps *T. tubifex* occurs in abundance in the profundal zone only in more oligotrophic lakes. However, it would seem to require an investigation of much wider scope to determine whether these are valid generalizations.

VERTICAL DISTRIBUTION OF OLIGOCHAETA IN LAKES

While the investigation just described was concerned primarily with worms of profundal regions, samples were taken at several shallower depths in two of the lakes. These samples were examined for evidence of depth differences in composition of the worm fauna, as has been reported for several British and European lakes (Brinkhurst 1964).

Benthic samples were taken from seven depths in Lake Geneva on a single date (Table 2). The samples from the two deepest stations (36.5 and 43.5 m) contained no macroscopic invertebrates. This is no doubt a result of prolonged anoxia in the deepest part of the basin. Vertical zonation of tubificid species was suggested by composition of the samples from the five lesser depths.

Two species, *Branchiura sowerbyi* and *Limnodrilus udekemianus* occurred only in the shallowest water, from 12.5 m in depth. Two others, *L. hoffmeisteri* and *Peloscolex multisetosus,* reached their maximum abundance in this sample. In addition to these four species, the sample contained immature specimens of at least one other. The most probable number of species was considered to be five, more than at any greater depth.

A sample from 17.5 m depth contained typical *L. hoffmeisteri* as well as *L. spiralis*. Of these, only *L. spiralis* was represented among mature specimens at greater depths. The 17.5 m sample also contained mature *Potamothrix hammoniensis* and *T. tubifex* and was dominated by unidentifiable immature specimens representing mostly or entirely *T. tubifex*.

At 21.0 meters the sample was dominated by immatures without hairs. The mature specimens in the sample can be assigned only to *L. spiralis*. *Potamothrix hammoniensis, Peloscolex multisetosus* and a relatively small number of immatures resembling *T. tubifex* were also found at this depth.

The sample from 24.5 m depth contained still fewer immatures with hairs and was dominated by mature *L. spiralis.*

Samples from 27.5 m indicated a fauna dominated by *T. tubifex;* the immatures with hairs are believed to represent mostly this species. Small numbers of *L. spiralis* and *P. hammoniensis* were also found (Table 2).

This series, while inadequate in that it represents only a single transect with single samples from most depths, provides evidence of vertical differences in composition of the worm fauna in a single lake. It is also clear that the paucity of species in profundal samples is due to the special conditions there and does not apply to the lake as a whole. While this series from Lake Geneva included at least seven species of tubificids only 3 were found at 27.5 m, the depth taken to represent the profundal (Table 3). Lastly, we may note that the proportion of mature individuals in some populations varies with depth; with numbers of mature *L. hoffmeisteri* exceeding immature specimens at 12.5 m, mature *Limnodrilus* spp. much less numerous than immatures at 17.5 and 21.0 m, and mature *L. spiralis* considerably more abundant than immatures at 24.5 m. A careful analysis of a situation of this sort through the course of a year could indicate more precisely the proportion of immatures attributable to each taxon and indicate conditions conducive to maturation and breeding of the species.

Samples taken in Devils Lake at three depths on several dates further illustrate vertical zonation of oligochaetes as well as seasonal variations in the abundance of some species. Samples taken on two dates at two nearshore stations (Table 4) included variable numbers of three species of naidids. Doubtless, a series of samples taken throughout the summer and winter would have reflected greater fluctuations in abundance. Muttkowski (1918) noted strong seasonal variation in abundance of naidids in Lake Mendota, with higher population densities associated with seasonal development of the littoral macrophytes.

Aulodrilus pluriseta in Devils Lake also seemed to undergo a seasonal change in abundance (Table 4). This is, in the extremes indicated here, unusual for a tubificid but apparently not unusual for *A. pluriseta.* In a series of samples taken monthly in two British lakes, Bala and Windermere, Brinkhurst (1964) found strong seasonal fluctuations in abundance of *A. pluriseta,* with maxima in mid- to late summer. He reported that very few sexually mature specimens were found and suggested that asexual

TABLE 4. ESTIMATES OF ABUNDANCE OF AQUATIC OLIGOCHAETES, AS INDIVIDUALS PER SQUARE METER, AT TWO NEARSHORE STATIONS ON DEVILS LAKE

	8.0 Meter Station — Date		10.0 Meter Station — Date	
	2 VI 70	19 X 69	2 VI 70	19 X 69
Naididae				
Arcteonais lomondi	22	133		44
Dero digitata	44			
Stylaria fossularis	44		22	
Total	110	133	22	44
No. species	3	1	1	1
Tubificidae				
Aulodrilus limnobius	22	89		
A. pigueti	22	178	178	44
A. pluriseta			1133	
Ilyodrilus templetoni	22			44
Potamothrix moldaviensis			22	
Undetermined immatures;				
with hair chaetae	22	89	22	
without hair chaetae		178	133	267
Total	88	534	1488	355
Apparent No. species	3	4	4	3

reproduction was occurring. In Bala Lake more breeding specimens were found, especially in late summer and this may be the time of a single annual period of sexual activity (Brinkhurst 1964). No breeding specimens were observed in the Devils Lake samples and the seasonal fluctuation is thus believed to be the result of rapid asexual reproduction.

On several dates naidids appeared in samples taken at a mid-lake station with a depth over 13 m. Maximum numbers were observed here in fall (Table 5), and may reflect active or passive movement, or both, of the worms from littoral areas as macrophytic vegetation died down. Most, if not all, naidids are capable of swimming.

Of the three *Aulodrilus* species found at the nearshore station, only *A. pigueti* was recorded from mid-lake (Table 5). To the best of my knowledge, swimming has not been recorded for *Aulodrilus* and dispersal may thus not occur as readily as with naidids.

Again, the full richness of oligochaete fauna of the lake was not reflected in profundal samples. While samples from Devils Lake have revealed six species of tubificids (Tables 4, 5) only three have been found at the mid-lake station (Table 5).

TABLE 5. ESTIMATES OF ABUNDANCE OF AQUATIC OLIGOCHAETES, AS INDIVIDUALS PER SQUARE METER, AT A MID-LAKE STATION ON DEVILS LAKE

	Date					
	8 III 70	21 V 70	2 VI 70	4 VIII 72	21 IX 69	19 X 69
Naididae						
Arcteonais lomondi		22			1555	
Dero digitata	44	67			1866	711
Ophidonais serpentina						89
Stylaria fossularis		22				
Total	44	111	0	0	3421	800
No. species	1	3	0	0	2	2
Tubificidae						
Aulodrilus pigueti		22	22			133
Ilyodrilus templetoni	44	44	67			
Limnodrilus hoffmeisteri	44		22	44		44
Undetermined immatures;						
with hair chaetae	178	156	222	111	400	44
without hair chaetae	1244	267	822	1056	1378	978
Total	1510	489	1155	1211	1778	1199
Apparent No. species	2	2	3	2	2	3

SUMMARY

This paper presents records of twenty-eight taxa of aquatic Oligochaeta from the inland waters of Wisconsin. Most of these were not previously reported from the state.

An investigation of the profundal oligochaete fauna in a series of lakes revealed no consistent correlation of abundance or species composition with lake type. In general, the profundal worm fauna is species poor; species other than *Limnodrilus hoffmeisteri, Ilyodrilus templetoni,* and *Tubifex tubifex* are seldom found.

Samples taken from shallower depths in two lakes provided evidence of vertical differences in composition of the worm fauna, with littoral samples containing species not found in the profundal benthos.

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A HISTORY OF THE VEGETATION OF EAU CLAIRE COUNTY, WISCONSIN

William J. Barnes
*University Wisconsin—
Eau Claire*

ABSTRACT

The General Land Survey records of ca. 1850 were used to reconstruct the vegetation of presettlement Eau Claire County. About 80% of the county was prairie, oak opening or barrens, while only 20% was forest. The prairies and oak openings occurred primarily south and west of the tension zone, while the barrens occurred on the sandy terraces of the Eau Claire River. The pineries and hardwood forests occurred for the most part at the eastern end of the county. Field samples and aerial photographs were used to note changes which have occurred over the last 120 years. Farmland and oak forest now occur where previously oak opening and prairie existed. This change is due to the relative richness of the soil and to the cessation of periodic fires. The forests have changed from being dominated by pine to having red oak and aspen as the most important species. The composition of the barrens has not changed greatly over the years, although the character of this vegetation type has changed from that of an opening of pine and oak to a closed forest.

INTRODUCTION

The first permanent settlers in the county came to what is now the city of Eau Claire in 1845. Eau Claire County was established in 1856, with a population of several hundred people. The majority of the first settlers were associated with the lumber mills at the confluence of the Eau Claire and Chippewa Rivers. The population grew rapidly during the early logging days, so that there were about 22,000 people in the county at the climax of the lumbering era, about 1900. Most of the early farms were located in the southern and western parts of the county, and agriculture changed from wheat, barley and rye to primarily dairying at about the turn of the century.

The character of the vegetation was described in early local newspaper accounts as, "The county is finely diversified with streams, timber, prairie and oak openings", and,

> The lands are mostly prairie, slightly rolling, and interspersed with an abundance of fine timber. We (City of Eau Claire) are located within 15 miles of the inexhaustible pineries, one lying on the Chippewa River, the other on the Eau Claire River.

One article written by a visitor to the city of Eau Claire includes the statement, "Your great want seems to be a lack of timber in the immediate vicinity", while other accounts indicate that some of the southern and western parts of the county were covered by "brush".

DESCRIPTION OF PRESENT EAU CLAIRE COUNTY

Eau Claire County is located in the west central part of the state at about 91° W, 45° N. It is rectangular in shape, being 18 miles from north to south (T25N to T27N) and 36 miles from east to west (R5W to R10W), a total of 648 square miles. The southwestern part of the county is quite broken and is part of the western upland, while the rest of the county is rolling and is part of the central plain (Fig. 1). The extreme southwestern portion of the county lies in the driftless area, while all of the remainder is covered by Illinoian drift (Martin, 1932). Elevations within the county range from 1000 to 1100 feet above sea level in most places, except in the lower terraces of the Chippewa and Eau Claire Rivers where they are about 800 to 900 feet above sea level.

Eau Claire County is covered by a deep layer of Mt. Simon and Eau Claire sandstone of Cambrian age. Glacial deposits cover all

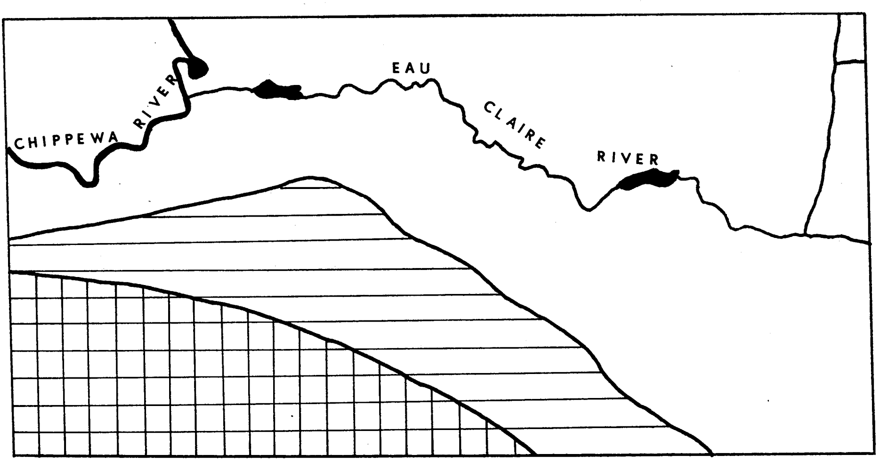

FIGURE 1. Geological provinces and glaciation in Eau Claire County. Vertical lines indicate the Driftless Area, the remainder is older Drift. Horizontal lines indicate the Western Upland, the remainder is the Central Plain.

but the driftless area and river valleys, and a layer of loess of varying thickness occurs throughout the county. About 85 soil types are represented in the county, most of which are sands, loamy sands, or silty sands.

Eau Claire County is of particular interest from a vegetational viewpoint, as the tension zone lies across the county from the northwest to the southeast (Fig. 2). The southern and western parts of the county belong to the prairie-oak forest province of southern Wisconsin, while the extreme northeastern part of the county is a part of the mixed conifer-hardwood province of northern Wisconsin. A major part of the county lies within the transitional zone between these two floristic provinces.

Climatic differences within the county are not great, although there is a tendency for the northeastern part to be cooler and more moist than the southwestern part for much of the year (Collins, 1968). Mean annual precipitation is 32 inches, the average date of the last killing frost is May 4, and the mean length of the growing season is 150 days (Barland, 1965).

METHODS

The species composition of the several vegetation types present at the time of the land survey (1847–1853) was determined by compiling data from photocopies of the original field notebooks of the surveyors, on file at the County Clerk's Office. Details of the type of record made by the surveyors can be found in Cottam (1949) and Bourdo (1956). The methods used for making qualitative and quantitative analyses of the surveyors' records and for

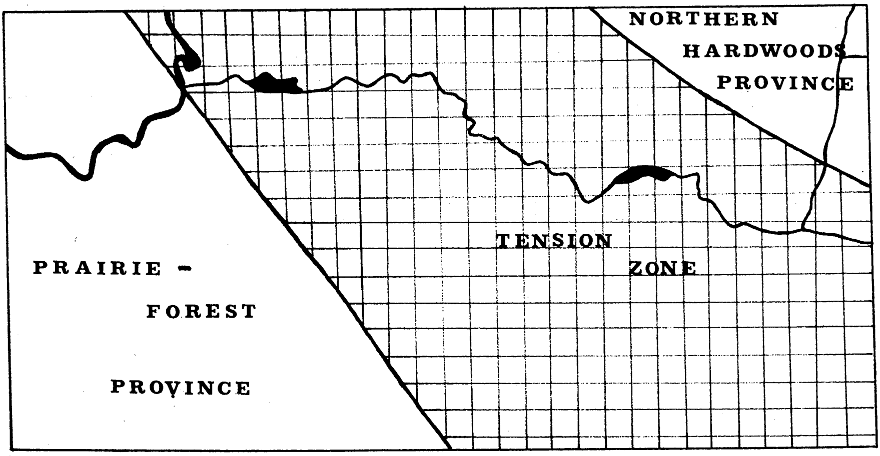

FIGURE 2. The tension zone in Eau Claire County.

preparing a vegetation map are described by Cottam (1949), Bourdo (1956) and Stroessner and Habeck (1966). In some cases the common names used for the species of trees were different from the names today. These are listed below as interpreted in this study.

Pitch pine—*Pinus banksiana* Lamb. (jack pine)
Black pine—*Pinus banksiana* Lamb. (jack pine)
Spruce pine—*Pinus banksiana* Lamb. (jack pine)
Yellow pine—*Pinus resinosa* Ait. (red pine)
Black oak—*Quercus velutina* Lam. (black oak)
or
Quercus ellipsoidalis Hill (Hill's oak)
or
Quercus borealis Michx. (red oak)
Jack oak—*Quercus ellipsoidalis* Hill (Hill's oak)
Water beech—*Carpinus caroliniana* Walt. (blue beech)
White maple—*Acer rubrum* L. (red maple)
Sugar maple—*Acer saccharum* Marsh. (sugar maple)
Lind—*Tilia americana* L. (basswood)
Ironwood—*Ostrya virginiana* K. Koch. (hop hornbeam)
White walnut—*Juglans cinerea* L. (butternut)

Seven deputy surveyors were involved in surveying Eau Claire County over a 6 year interval. Thus a species may have been given more than one common name. Several cases of two or more species given the same common name occur in the surveyors' records. None of the surveyors differentiated between *Populus tremuloides* and *P. grandidentata,* both were simply called "aspen". However, this does not represent a serious limitation to interpretation of the vegetation, as the ecological behavior of these two species is very similar. However, the name "black oak" was apparently applied to *Quercus velutina, Q. ellipsoidalis* and *Q. borealis.* Since these three species of oak have quite different ecological behaviors, the failure of the surveyors to differentiate does present a problem in the interpretation of their records.

Field samples of the tree composition were taken during the summer of 1973, using the quarter method (Cottam and Curtis, 1956). From 150 to 200 points were sampled in the forested areas, while 40 points were used in sampling an oak forest in an area which was mapped as being an oak opening in ca. 1850. Sampling stations were located on a map of the public properties of the county, and only those stands which showed no signs of recent disturbance were used. Only trees with a dbh of 4 inches or more were recorded, although field notes of the character of the understory and sapling frequencies were also kept.

VEGETATION TYPES

Mapping

When the surveyors established a section or quarter section point, they measured the distance and compass bearing to the nearest tree in each of 4 quadrants in the case of corner points on the exterior township lines, or to the nearest tree on each side of the line at all other points in the township. These data, along with the common names of the trees and their diameters at breast height (dbh) were then recorded in their field books. If there were no trees nearby, they constructed a mound of earth and sod, and so stated. Every major change in vegetation, trees which occurred directly on the line, rivers, streams, ponds, lakes, caves, abrupt topographical changes, windfalls, etc., were noted in their records. Also, at the end of each section line they wrote a brief description of the mile they had just traversed. From these data, a map of the vegetation of the county, as it appeared in ca. 1850, was constructed (Fig. 3).

Differentiation between prairies, oak openings, barrens and forests is made on the map. Wetlands are not extensive in the county, occurring for the most part at the heads of smaller streams. Prairies are defined as areas with less than one tree per acre. Thus, all corners at which mounds had been constructed, or at which the distance between trees was a minimum of 209 feet, were mapped as prairies, providing this was consistent with section line descriptions. All areas in which the trees were less than 209 feet apart but greater than 50 feet apart, or if the section line description was appropriate, were mapped as oak openings if the trees were predominantly oak, or barrens if the trees were predominantly pine. When the trees were found to be less than 50 feet apart, the area was mapped as forest.

Prairies

The area mapped as prairie represents the single most extensive type of vegetation in the county at the time of settlement. Of the 2,053 points established in the county by the surveyors, 888 (44%) were mapped as prairie. The greatest expanse of prairie occurred in the central part of the county, south and west of the alluvial terraces of the Eau Claire River. Here several whole townships were nearly devoid of trees. The prairies, and the oak openings, occur primarily south of the tension zone, on the western uplands.

Unfortunately, the surveyors rarely included any information on the herbaceous species present in their field notes. Most section line descriptions simply state "nothing but grass on it", "rolling prairie", "level prairie", or "first rate prairie". A substantial

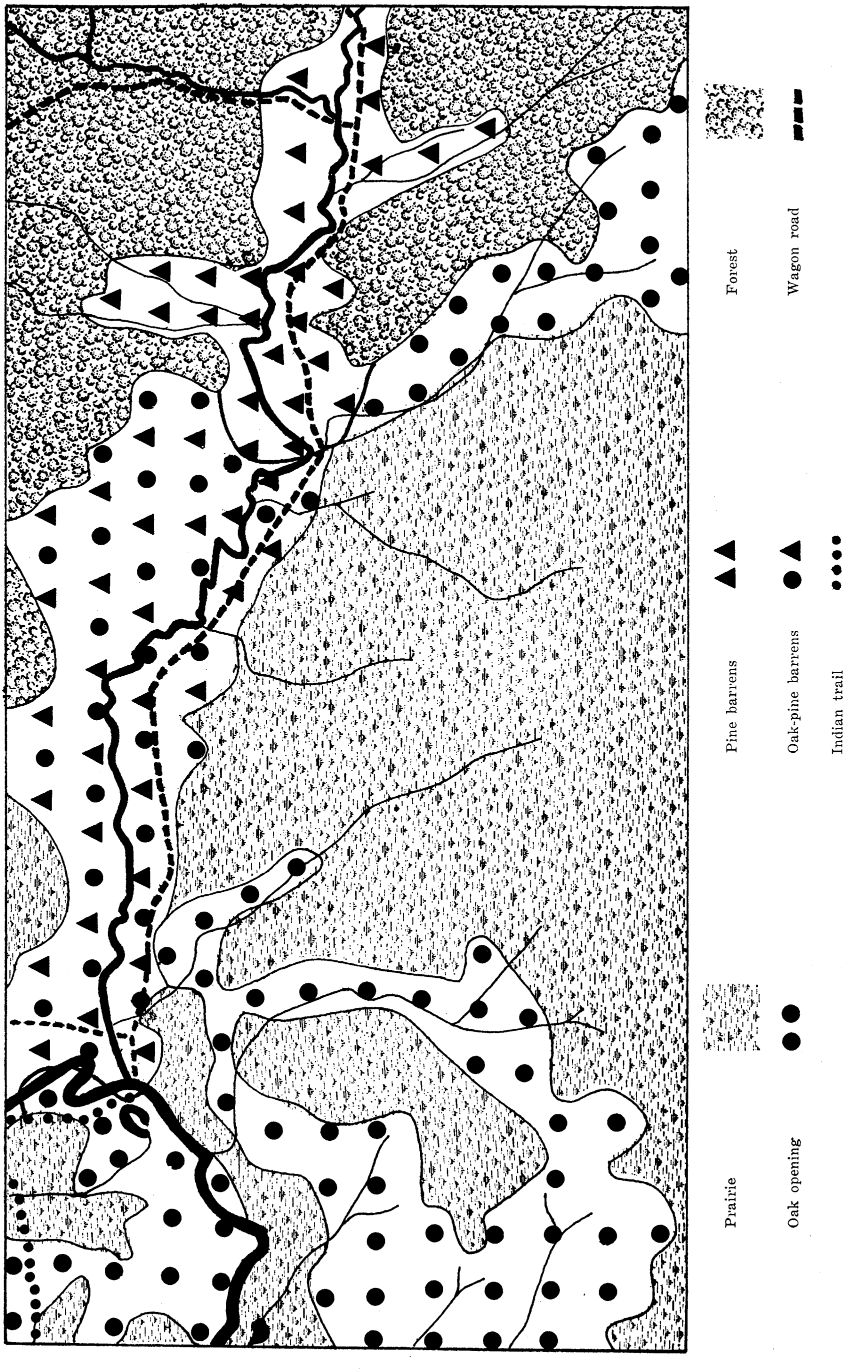

FIGURE 3. The vegetation of Eau Claire County in ca. 1850.

number of section line descriptions indicated that much of the area mapped as prairie had various amounts of oak scrubs present. Included were descriptions such as "some oak brush", "scattering oak bushes", "oak bushes", and sometimes, "considerable oak brush", or "covered with oak brush".

Some insight as to the species which occurred on these prairies may be inferred from Buss' study (1956) of plant succession on the Meridean Prairie in adjacent southeastern Dunn County. He found that the most abundant plants occurring on sites undisturbed for at least 35 years were *Andropogon gerardi* Vitm., *Tradescantia ohiensis* Raf., and *Euphorbia corollata* L. Species listed as being common or numerous include *Stipa spartea* Trin., *Phlox pilosa* L., *Artemisia ludoviciana* Nutt., *Solidago rigida* L., *Liatris scariosa* Willd. and *L. pycnostachya* Michx. *Andropogon scoparius* Michx., *Sorghastrum nutans* Nash., *Petalostemum purpureum* Rydb., and *P. candidum* Michx. are species Buss listed as being scattered. Of the trees which were recorded on the prairie, 41.1% were bur oak, 36.8% were black oak, 9.7% were white oak, while 8.1% were aspen.

The presence of large tracts of prairie in the Middle West has been attributed to periodic burning (Gleason, 1913), and Curtis (1959) discusses in some detail the role of fire in maintaining the prairies of southern Wisconsin. Fire undoubtedly was responsible for the prairies in Eau Claire County. H. A. Towne, (Barland, 1965) in discussing an elk hunt near Eau Claire in 1857, provides the following description. "The low ground was covered at the time by dense poplar thickets, through which the prairie fire would run every few years killing them but leaving the dead young trees still standing until a new fire should sweep the country, and find the dry timber and consume them". E. T. Sweet (1875), a geologist, gives the following description of prairies located northwest of Eau Claire near St. Croix, Wisconsin.

> Analogous to the barrens are areas known as brush prairies and simply prairie. In some of these prairies, young trees are springing up, and bid fair, if undisturbed, to attain the usual size. These are appealed to as examples of prairies returning to forest, since annual fires are no longer permitted to ravage the region. So far as these areas are concerned, the appeal seems to be well taken, save that we might, perhaps, justly dissent from the use of the word prairies as applied to them; for there seems to be no evidence that these ever were prairies in the sense of being completely and compactly covered by prairie grass, to the exclusion of all shrubs and stubs of arboreous plants, as in the case of true prairies. They rather appear to have originally been open forest areas, which, on account of the character of the soil, were especially subject to dryness, thus to destructive action of annual fires; while moister adjoining areas escaped. On the cessation of the destructive agent, they appear to be returning to their normal condition.

The fact that much of the area, which was prairie at the time of settlement, now bears tree growth supports the contention that fire was responsible for the prairies of Eau Claire County.

No attempt was made in this study to take a contemporary sample of the vegetation of the area mapped as prairie. However, inspection of aerial photographs shows that most of the area is presently under cultivation. Oak forests now occur throughout the area, usually in the shapes of squares, rectangles, or other geometric forms, or are elongated and irregular and occur on the steeper slopes or along streambeds.

Oak Openings

The oak openings occurred primarily in the southern and western parts of the county in association with the prairies. Differentiation between prairie and oak opening was often difficult, and the resulting boundaries are somewhat arbitrary. A total of 384 of the corner points in the county (19%) are mapped as oak opening.

Section line descriptions of the oak openings again gave no information concerning the herbaceous species, although it is presumed they were not much different from those of the prairies. "Some scattering oak trees", "some oak timber", "scattering oak", "timber scarce", or, "oak barrens", are typical section line descriptions.

The average distance between trees was 90 feet, which is about 5 trees per acre. Of the 12 species of trees recorded by the surveyors, the most common species by far were black oak, with a relative density of 38.5%; bur oak, 35.0%; and white oak, 16.4%. The majority of these oaks had a dbh of from 8 to 12 inches.

Like the prairies, the oak openings were probably maintained by fire. Muir (1913) described the oak openings in southern Wisconsin as open and sunny. He indicates that the oak forest developed from the oak openings upon settlement by white man and the subsequent cessation of fires. Cottam (1949) studied the history of an oak forest in Dane County, Wisconsin, which was once an oak opening. He came to the conclusion that it was fire, rather than a change in climate, disease, or some other factor, that was responsible for the oak openings at the time of settlement.

The major tracts of oak openings occurred along streams, especially Lowe's Creek and Otter Creek in the southwestern part of the county, and Bridge Creek in the southeastern part of the county. Similar patterns of oak opening distributions are apparent in the studies of the vegetational histories of Beloit Township (Rock County) by Ward (1956), of Dodge County by Neuenschwander (1957), and of Racine County by Goder (1956). The patterns of distribution of the oak openings are probably related to the reduced frequency and/or severity of fires in these moister regions compared to the surrounding uplands where almost no mature trees were present.

A sample of 40 quarter points were taken in what is presently an oak woods adjacent to Lowe's Creek in Section 4, T25N, R9W. Although this sample is too small to place much statistical confidence, it is probably sufficient to provide some insight into the major changes in the vegetation of this region, which have occurred since settlement.

The most obvious change in the oak openings is the change in absolute density of the trees, from 5.4 trees per acre in ca. 1850 to 235 trees per acre in 1973. The major change in composition is the increase in relative density of black oak, and the corresponding decrease in relative density of bur oak (Table 1). Curtis (1959) states that bur oak is more resistant to fire than black oak, which would seem to provide a reasonable explanation for the opposite change in relative density of these two species, since the time of settlement and the cessation of periodic fires. Other species did not occur in sufficient numbers, either in the surveyor's records or in the 1973 sample, to permit interpretation in any detail.

The oak woods present in Section 4 today is completely dominated by black oak, in terms of frequency of occurrence and relative size, as well as relative density. Distribution of the size classes of black oak is presented in Fig. 4. The rather large number of trees in the lower size classes and the absence of many saplings of any other species indicate that no major change in the composition of this woods is likely to occur in the near future.

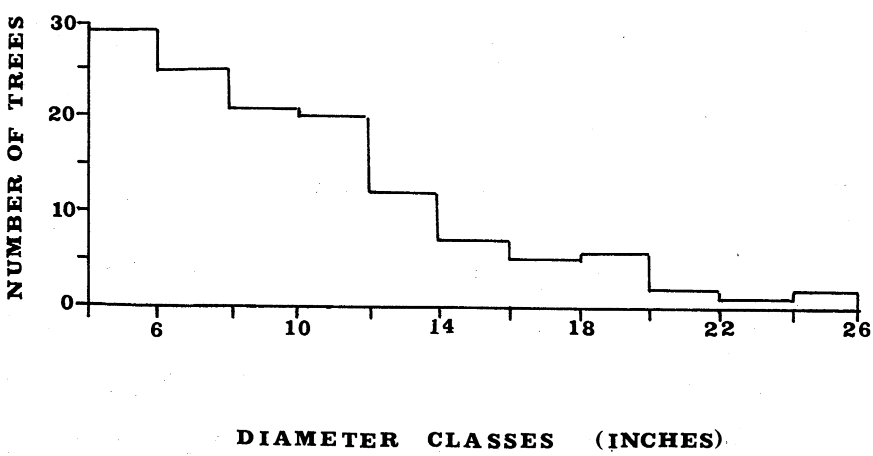

FIGURE 4. Size class distribution of black oak (*Quercus velutina* Lam.)

TABLE 1. COMPARISON OF RELATIVE DENSITY AND DIAMETER AT BREAST HEIGHT OF TREES IN THE OAK-OPENINGS IN CA. 1850 AND 1973

Species	1850 $\bar{x}$dbh	1850 % R.D.	1973 $\bar{x}$dbh	1973 % R.D.
Pinus strobus	15.0	0.9	—	—
Pinus resinosa	12.2	1.7	—	—
Pinus banksiana	9.5	1.7	—	—
Quercus alba	9.7	16.4	14.8	4.4
Quercus velutina	9.3	38.5	11.2	81.2
Quercus macrocarpa	8.7	35.0	8.7	11.9
Betula papyrifera	8.7	1.2	4.2	1.3
Populus sp.	10.8	3.4	6.4	0.6
Ulmus sp.	12.0	0.1	—	—
Acer sp.	11.7	0.8	4.1	0.6
Fraxinus sp.	10.0	0.1	—	—
Prunus serotina	9.3	0.2	—	—
		100.0		100.0

The Oak-Pine Barrens

Most of the sandy stream benches along the western two-thirds of the Eau Claire River were apparently occupied by a mixture of oak and pine in ca. 1850. This is mapped as the oak-pine barrens. The area includes 249 corner points, about 12% of the total for the county. These barrens were very heterogeneous, with the oak and pine generally forming a mosaic of separate stands of various sizes. The mean distance between trees was calculated to be 86 feet, or 5.9 trees per acre, which is similar to the values obtained for the oak openings. However, the variability of the distances in the oak-pine barrens (Coefficient of Variation of 102%) is much greater than that of the oak openings (c.v. of 67.5%). This indicates that the barrens were open areas that contained few trees interspersed with rather dense stands.

E. T. Sweet (1875) wrote the following description of the barrens of northwestern Wisconsin.

> The trees are either scrub-pine or black-jack oak, averaging in diameter about three or four inches and in height not over fifteen feet. In some places, as in the sand hills of the barrens, the trees are at considerable distances from each other, and in other places the little scrub pines, not over two inches in diameter, are so close together as to constitute a nearly impenetrable thicket. On the sides of the barrens, and in low places, quite large groves of norway pine are frequently found.

Moses Strong (1876), state geologist, described the barrens near St. Croix, Wisconsin as follows:

> The timber occupying these tracts is peculiar and does not justify the application of the term barrens. Some portions are covered with scrub pine

> to the exclusion of all else save underbrush. Most nearly similar are the patches of norway pine. Other areas are covered with burr, black and even white oak bushes, with occasional trees of these species.... There are also areas where white pine occurs.

Section line descriptions of this area varied considerably and included such entries as "scattering spruce pine", "scattering oak", "scrub oak", "nearly barren", "timber small pine, quite thick", "some small pine on east one half, west one half oak barrens", and, "sparse pine timber, undergrowth of jack oak".

Of the total of 157 jack pine trees recorded, 91, or 58%, were in the 9 to 10 inch diameter class. Moreover, the diameters of the trees at any given point rarely deviated by more than an inch or two, although the diameters of this species ranged from 5 to 15 inches in these barrens. Red pine also apparently occurred in even-age stands, while white pine was recorded primarily from corner points near the Eau Claire River or in other low places. These even-age stands of jack and red pine and the extensive areas of oak shrubs attest to the fact that these barrens, like the prairies and oak openings, were subject to periodic burning.

The 1973 composition of the oak-pine barrens was estimated using 200 quarter points in 20 stands scattered throughout this region. The results are presented in Table 1, along with comparative values obtained from the surveyors' records. The major difference in composition is the large decrease in red and white pine, and the corresponding increase in the relative density of jack pine. The decrease in red and white pine is due to logging in the latter half of the 19th century. Jack pine and Hill's oak saplings presently occur in most of these stands, while white pine saplings are infrequent, and saplings of red pine are rare. Another major difference in composition between these two eras is the increase in relative numbers of Hill's oak and decrease in the numbers of white oak. Apparently the openings created by logging, and the fires that burned through the slashings, have favored the spread of jack pine and Hill's oak, at the expense of red and white pine and white oak.

Some of this change in composition, especially with respect to the oaks, may be due to another factor. Although much of this area is presently county owned, some of it is private property under cultivation. These private properties, which were not included in the sample, represent some of the better soils, and their inclusion would in all probability, have yielded higher values for white oak and lower values for Hill's oak. Recalculation of the composition of the oak-pine barrens in ca. 1850, using data only from corner points in areas which are presently county owned, did in fact give somewhat lower values for white oak and higher values for Hill's oak.

The average diameter of all trees in ca. 1850 was 11.1 inches, while in 1973 it is 8.6 inches. However, since the surveyors had a decided preference for large trees (Bourdo, 1956), the mean diameter of the trees has probably not changed very much over this time interval. Relative density of the species present today and their diameter class values suggest little future change in the composition of the vegetation of this area.

The Pine Barrens

The area mapped as pine barrens is continuous with the oak-pine barrens and occurs along the Eau Claire River in the eastern part of the county. The major difference between these two vegetation types is the increase in relative proportions of pine over oak. The three species of pine constituted 80.1% of all the trees present, while the oaks accounted for only 10.6%. The variability of the tree distances (c.v. of 101%), and section line descriptions by the surveyors, indicate that, like the oak-pine barrens, this area contained numerous, relatively dense stands of pine interspersed over an otherwise rather open landscape. A total of 116 corner points (5%) are mapped as pine barrens in the county.

Section line descriptions by the surveyors included such entries as "scattering pine and pine barrens", "timber black and yellow pine", "timber black, yellow and white pine", and, "white and yellow pine, first rate". Other descriptive notations included "Enter black pine barrens", "Leave barrens, enter creek bottom", "Leave timber, enter barrens", and, "Leave bottom of Eau Claire River and enter black pine barrens".

White and red pine were apparently far more abundant in the pine barrens than in the oak-pine barrens. However, there seems to have been some bias by the surveyors in choosing white and red pine as witness trees. The mean distance of any given species from the corner points should be the same as for any other species, regardless of its density or frequency of occurrence. Yet, the mean distance from corner points of 41 white pine trees was calculated as 103.5 links (link = 0.67 feet); for 89 red pine trees it was 90.5 links, while for 62 jack pine trees it was found to be only 72.9 links. The average distance for all trees was computed as 87.6 feet. The probability of obtaining such deviations by chance alone is less than 10%. Also, the surveyors recorded all large trees which occurred directly on the section lines. These represent a small, but unbiased, sample of the relative density of each of the species. In comparing these values to the corner point data, it was found that the relative density of white pine on section lines was 28.6%, while at the corner points it was 37.0%. The comparable values for red pine were 42.9% and 49.3%, and for jack pine they were 7.1% and 4.1%. Thus, this apparent bias by the surveyors results in somewhat of an overestimate of white pine, and to a lesser degree, of red pine, and thus underestimate of the relative density of jack pine in the pine barrens.

Comparative values of the composition of the pine barrens are given in Table 2. Like the oak-pine barrens, the major difference in composition of the pine barrens from ca. 1850 to 1973 is the reduction in numbers of white and red pine, and the corresponding increase in the relative density of jack pine. There has been a noticeable increase in oak, as the relative density of the species listed as black oak by the surveyors has changed from only 3.0% in ca. 1850 to 19.1% in 1973. The "black" oak present in this area today is always *Quercus borealis*. When one compares tree diameters for these two time periods it is apparent that many large individuals of white and red pine have been replaced by many smaller individuals of jack pine and red oak.

Jack pine stands in this area are presently composed of individuals of rather small size, and do not contain many saplings of other species. The red oaks are present in all size classes and no one or two species of saplings occur consistently in the understory.

TABLE 2. COMPARISON OF RELATIVE DENSITY AND DIAMETER AT BREAST HEIGHT OF TREES IN THE OAK-PINE BARRENS IN CA. 1850 AND 1973

	1850		1973	
Species	$\bar{x}$dbh	% R.D.	$\bar{x}$dbh	% R.D.
Pinus strobus	14.1	15.2	14.1	2.4
Pinus resinosa	12.1	14.2	8.8	0.8
Pinus banksiana	10.0	33.2	7.0	55.3
Quercus alba	11.6	8.3	12.1	0.4
Quercus ellipsoidalis	9.2	10.2	9.5	28.4
Quercus macrocarpa	9.0	7.6	6.8	7.1
Acer rubrum	11.8	1.3	7.1	1.8
Populus sp.	10.7	7.6	7.5	2.5
Tilia americana	12.0	0.2	—	—
Betula papyrifera	10.4	1.5	7.0	0.8
Fraxinus sp.	10.0	0.2	—	—
Ulmus sp.	10.0	0.6	9.1	0.1
Prunus serotina	—	—	5.3	0.4
		100.0		100.0

Thus, no clear future successional trend is apparent in this vegetational type.

Forests

With the exception of the sandy alluvial terraces along the Eau Claire River, the far eastern part of the county was occupied by forests. It seems probable that the location at the eastern end of the county, the heavier soils, and the more numerous wetlands in this area greatly reduced the frequency of fire, thus permitting a forest to develop. Because of differences in composition, this forested region is separated into a south forest, south of the Eau Claire River, and a north forest.

South Forest

A total of 159 corner points (8%) were recorded in the south forest. The mean distance between trees was found to be 30.9 feet, which is only about 46 trees per acre. This low density value is due, to a large degree, to the failure of the surveyors to include many trees in the 4 to 8 inch diameter class as witness trees, as it was difficult to inscribe the required corner identification information on them. Since these smaller trees usually represent a substantial portion of the trees present in a forest, their inclusion would have resulted in a smaller mean distance, and subsequently a higher absolute density.

The character of the south forest was that of a closed forest, with the exception of the rather numerous windfalls. Twenty-two

TABLE 3. COMPARISON OF RELATIVE DENSITY AND DIAMETER AT BREAST HEIGHT OF TREES IN THE PINE BARRENS IN CA. 1850 AND 1973

Species	1850		1973	
	x̄dbh	% R.D.	x̄dbh	% R.D.
Pinus strobus	15.1	19.2	12.8	6.6
Pinus resinosa	12.6	36.1	12.1	3.6
Pinus banksiana	9.2	24.8	6.8	48.0
Quercus alba	10.4	5.3	9.3	5.9
Quercus borealis	15.1	3.0	8.0	19.1
Quercus macrocarpa	10.0	2.3	6.1	2.4
Acer rubrum	10.2	2.3	6.1	5.9
Populus sp.	7.2	1.9	7.2	5.1
Tilia americana	9.0	0.8	—	—
Betula papyrifera	7.6	2.6	5.9	3.1
Fraxinus sp.	5.0	0.4	4.0	0.3
Ulmus sp.	17.0	1.1	—	—
Prunus serotina	10.0	0.4	—	—
		100.0		100.0

of the 159 corner points, 13.8%, were located in windfalls. A characteristic descriptive entry in the field notes is:

16:00 Leave swamp and enter windfall, bears N and S
40:00 Set post for ¼ sec. corner
W. Pine 16″ S89E 592 links
No other tree near
55:00 Leave windfall, bears N and S

Some characteristic section line descriptions of these windfalls included "Timber dead pine", "Timber mostly dead and fallen", and, "Undergrowth in windfall brush and briars". White pine was the most frequently used witness tree in these windfalls, and the soil types were mostly wet alluvial soils, Elm Lake loamy sand and Adrian mucky peat, which are poorly drained soils. The significance of the role of windfalls in perpetuating the diversity of the mixed conifer-hardwood forests of northeastern Wisconsin has been discussed by Stearns (1949), and windfalls appear to have been of equal importance in the forests of Eau Claire County. The site of some of these windfalls was examined in the summer of 1973, and tip-up mounds, left by the uprooted trees, are still in evidence in some places.

Table 4 indicates that major compositional changes have occurred in this vegetation type since settlement. The relative density of white pine has dropped from 43.6% to 6.7%, and its average diameter has changed from 18.7 inches to 9.3 inches. The relative

TABLE 4. COMPARISON OF RELATIVE DENSITY AND DIAMETER AT BREAST HEIGHT OF TREES IN THE SOUTH FOREST IN CA. 1850 AND 1973

Species	1850 $\bar{x}$dbh	1850 % R.D.	1973 $\bar{x}$dbh	1973 % R.D.
Pinus strobus	18.7	43.6	9.3	6.7
Pinus resinosa	13.3	9.0	19.0	0.5
Pinus banksiana	12.0	0.7	7.7	6.0
Quercus alba	12.0	13.2	8.6	7.2
Quercus borealis	12.1	6.9	8.8	30.7
Quercus macrocarpa	—	—	5.5	1.3
Acer rubrum	10.3	10.4	5.9	17.3
Populus sp.	11.2	3.8	7.3	22.7
Betula lutea	12.5	2.8	—	—
Betula papyrifera	11.0	8.0	6.1	7.7
Ostrya virginiana	8.0	0.4	—	—
Ulmus sp.	9.7	1.0	—	—
Prunus serotina	8.0	0.4	—	—
		100.0		100.0

density of red pine has decreased from 9.0% to 0.5% and, as in the barrens, there has been a corresponding increase in the relative number of jack pine. However, unlike the barrens, the increase in relative density of jack pine has not been great, from 0.7 to 6.0%. The two species which exhibit the greatest increase in relative density are red oak and aspen, with gains of 6.9 to 30.7% and 3.8 to 22.7% respectively.

The average diameter of all trees recorded in ca. 1850 was 15.1 inches, compared to a mean of 7.9 inches of 600 trees measured in 1973. Part of this difference is undoubtedly due to the surveyors' avoidance of very small trees. Nevertheless, the difference is great enough to indicate a major change in the structure of this forest between these two time periods.

Possibly indicative of a future successional trend are the many small individuals of red maple and their numerous saplings which are common in the south forest. However, many small individuals of red and white oak are also present, thus no great change in the composition of this forest seems likely in the near future.

North Forest

A total of 255 corner points (12%) were mapped in the north forest. This community type is the only one in the county lying north of the tension zone. It differs from the south forest primarily in the presence of sugar maple and basswood in the canopy and a higher frequency of witch-hazel (*Hamamelis virginiana* L.), hornbeam and blue beech in the understory. Also, the dominance by white and red pine was not nearly as great here (combined relative density of 28.6%) as in the south forest (52.6%).

The mean distance between trees in the north forest, 26.7 feet, was somewhat less than that of the south forest. The mean diameter of the trees in the south forest was somewhat greater (15.1 inches) than that of the north forest (13.2 inches) due to the greater number of white pine trees in the south. Some of these white pine were 48 inches dbh at the time of the survey, and many were 24 to 30 inches. Large fire scarred stumps of pine are still in evidence in both of these forests today. Basal area was nearly identical in the two forests, about 58 square feet per acre in the south and 59 in the north.

Windfalls were also extensive in the north forest, occurring at 24 (9.4%) of the 255 corner points. Like the south forest, most of these windfalls were apparently downed pine which had developed on poorly drained soils.

The comparative composition of the north forest is given in Table 5. Again, a drastic reduction in the relative number of pine has occurred, with a corresponding increase in red oak trees. Other

TABLE 5. COMPARISON OF RELATIVE DENSITY AND DIAMETER AT BREAST HEIGHT OF TREES IN THE NORTH FOREST IN CA. 1850 AND 1973

Species	1850 $\bar{x}$dbh	1850 % R.D.	1973 $\bar{x}$dbh	1973 % R.D.
Pinus strobus	17.0	24.8	5.0	0.1
Pinus resinosa	14.8	3.8	5.0	0.5
Quercus alba	12.7	10.4	7.6	16.5
Quercus borealis	11.8	8.0	8.8	43.4
Acer rubrum	11.6	12.0	5.9	12.0
Acer saccharum	10.8	14.0	6.6	1.1
Populus sp.	12.4	7.4	7.3	15.0
Tilia americana	11.7	2.6	5.3	0.4
Betula lutea	10.6	5.6	—	—
Betula papyrifera	12.0	4.0	5.8	10.1
Ostrya virginiana	7.4	1.0	5.0	0.2
Fraxinus sp.	11.2	2.6	5.4	0.5
Ulmus sp.	11.1	3.2	10.1	0.3
Prunus serotina	—	—	5.0	0.1
Carya cordiformis	7.3	0.6	—	—
		100.0		100.0

species which have increased in number appreciably are aspen and white birch. The relative density of sugar maple has decreased from 14.0% in ca. 1850 to 1.1% in 1973. However, the reason for this reduction is probably a parallel of the situation of white oak in the oak-pine barrens. That is, sugar maple occurred primarily on richer soils (especially Withee sandy loam and Loyal loam), and these are the soils now under cultivation, i.e. no longer forested.

Red maple is presently the most abundant small tree in the north forest, with individuals occurring in 54% of the quarter points, and saplings occurring in every stand sampled in 1973. This would seem to indicate a successional trend toward red maple stands in the future. However, the relative density of large individuals of this species has not changed since ca. 1850 (12%), making such a prediction somewhat tenuous.

SUMMARY

Records of the surveyors (ca. 1850) indicate that approximately 80% of Eau Claire County was prairie, oak opening and barrens, while only about 20% was forest. The prairies and oak openings occurred in the south and west, the oak-pine and pine barrens occurred for the most part on the terraces of the Eau Claire River,

while the forests occurred in the extreme eastern part of the county. This open nature of most of the vegetation was almost surely due to fire.

The forests, although escaping destruction by fire, were subjected to another catastrophe, windstorms. About 11% of the corner points in the forests were recorded as being in windfalls at the time of settlement. These occurred primarily in the white pine stands which had developed on poorly drained soils.

Some of the patterns of the vegetation as it existed in ca. 1850 are related to the tension zone. Most of the area south of the tension zone was prairie or oak opening, while the area north of the zone was forested. The area within the tension zone was very heterogeneous and included all of the vegetation types discussed in this study. However, the largest part of the tension zone occurs on sandy outwash, which was dominated by the pines, especially jack pine.

The relationship between the vegetation as it existed in ca. 1850 and contemporary land use patterns is quite apparent. Regions previously prairie and oak openings are now predominantly farmland. The oak-pine and pine barrens, as well as some of the forests, are presently county-owned forest.

The major portion of the vegetation of Eau Claire County at the time of settlement was open, or dominated by species of trees of low shade tolerance. This indicates the importance of fire, and to a lesser extent, windstorms, on the development of the vegetation prior to settlement by white man. With settlement came the cessation of prairie fires and the cutting of the pineries. This caused forests to spring up on what was once prairie and oak opening, and the forests to change in composition from those dominated by white and red pine to dominance by oak and aspen. The vegetation of the barrens has shown the least amount of change in composition, although the character of this vegetation type has changed to a more closed form.

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ADDRESSES OF THE AUTHORS

LOUIS W. BUSSE, School of Pharmacy, Univ. Wisconsin—Madison 53706

THOMAS FOSTER GRITTINGER, Univ. Wisconsin, Sheybogan Center, P.O. Box 719, Sheboygan, Wis. 53081

WARREN R. WADE, Univ. Wisconsin—Stout, Menomonie, Wis. 54751

WILLIAM STEUBER, 705 Schiller Court, Madison, Wis. 53704

PAUL C. BAUMANN, JAMES F. KITCHELL, JOHN J. MAGNUSON and TERRENCE B. KAYES, Dept. Zoology, Zoology Research Bldg. (P.C.B.), and Limnology Lab., Univ. Wisconsin—Madison 53706

ROBERT T. BALMER, College Engineering and Applied Science, Univ. Wisconsin—Milwaukee 53201

EDWARD E. POPP, 543 N. Harrison St., Port Washington, Wis. 53074

J. W. MERTINS and H. C. COPPEL, Dept. Entomology, Univ. Wisconsin—Madison 53706

WILLIAM C. SONZOGNI and G. FRED LEE, Laboratory Water Chemistry, Univ. Wisconsin—Madison 53706 and Institute Environmental Sciences, Univ. Texas—Dallas, P.O. Box 30365, Dallas, Tex. 75230

JON C. COOPER, G. FRED LEE and ANDREW P. DIZON, Limnology Laboratory, Univ. Wisconsin—Madison 53706 and Univ. Texas—Dallas, P.O. Box 30365, Dallas, Tex. 75230

G. FRED LEE and WILLIAM WILSON, Univ. Texas—Dallas, P.O. Box 30365, Dallas, Tex. 75230

G. E. HENDRICKSON and R. L. KNUTILLA, U.S. Geological Survey, Madison, Wis. and Okemos, Mich. offices respectively

THOMAS D. BROCK and JAMES HOFFMANN, Dept. Bacteriology, Univ. Wisconsin—Madison 53706

WILLIAM DILWORTH, 23 Minnie Ave., Beloit, Wis. 53511

JAMES LA MALFA, Univ. Wisconsin Center, Marinette County, Marinette, Wis. 54143

RICHARD A. KARSTEN, HAROLD McCONNELL and THOMAS D. PATTERSON, Dept. Community Affairs, Univ. Wisconsin Extension, 9722 W. Watertown Plank Rd., Milwaukee 53226 and Dept. Geography, Florida State Univ., Tallahassee 32306 and Dept. Geography, Northern Illinois Univ., DeKalb, Ill. 60115

ARTHUR MARSHALL, 125 East Gilman St., Madison, Wis. 53703

THEODORE S. COCHRANE and PETER J. SALAMUN, Dept. Botany-Herbarium, Univ. Wisconsin—Madison 53706 and Dept. Botany-Herbarium, Univ. Wisconsin—Milwaukee 53201

PETER J. SALAMUN and THEODORE S. COCHRANE, Ibid

BRIAN G. MARCKS, Dept. Environmental Quality and Conservation, Horvard, Needles, Tammen and Bergendorff, Alexandria, Va.

MARY ELLEN ANTONIONI, 6318 Piping Rock Rd., Madison, Wis. 53711

OMAR M. AMIN and WAYNE H. THOMPSON, Univ. Wisconsin—Parkside, Kenosha, Wis. 53140 and Univ. Wisconsin—Madison and State Laboratory of Hygiene, Madison 53706

OMAR M. AMIN, Ibid, senior author above

LAVERNE C. STRICKER and ROBERT N. CHEETHAM, JR., USDA Soil Conservation Service State Office, 4601 Hammersley Rd., Madison, Wis. 53711

RICHARD P. HOWMILLER, Dept. Biological Science, Univ. California—Santa Barbara, Santa Barbara, Calif. 93106

WILLIAM J. BARNES, Univ. Wisconsin—Eau Claire, Eau Claire, Wis. 54701