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TRANSACTIONS of the Wisconsin Academy of Sciences, Arts and Letters

Volume 82 • 1994

Transactions welcomes articles that explore features of the State of Wisconsin and its people. Articles written by Wisconsin authors on topics other than Wisconsin sciences, arts and letters are occasionally published. Manuscripts and queries should be addressed to the editor.

Submission requirements: Submit three copies of the manuscript, double-spaced, to the editor. Abstracts are suggested for science/technical articles. The style of the text and references may follow that of scholarly writing in the author's field, although author-year citation format is preferred for articles in the sciences, author-page number format for articles in the humanities. Please prepare figures with reduction in mind.

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Errata

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Because of a change in font made by the printer at the final typesetting, the ≤ symbol was lost, causing a major problem in data interpretation on page 55 of the article "Recent changes in the aquatic macrophyte community of Lake Mendota," by Elisabeth R. Deppe and Richard C. Lathrop. For a copy of the corrected page, please contact the Wisconsin Academy.

From the editor

All of us who read *Transactions*, whether for the first time or as old friends well acquainted with this journal, cannot help but notice that the content of articles published year after year leans heavily toward the natural sciences. While *Transactions* extends a broad invitation welcoming scholarly articles "that explore features of the State of Wisconsin and its people" and while the Wisconsin Academy is devoted to arts and letters as well as to the sciences, it is a fact that *Transactions* has been a publishing vehicle of choice for those who write about the land and waters of Wisconsin, its geology, geography, and the diversity of its life forms. This is explainable in some measure insofar as historians, artists, poets, and creative writers often choose to write for our sister publication, the *Wisconsin Academy Review*, a journal of Wisconsin culture.

This 1994 issue of *Transactions* is no exception to the rule. Some of our articles feature studies of jaguars at the Milwaukee Zoo and black bear habitat in northeastern Wisconsin, the plant communities of Nine-Mile Island in the Chippewa River and the mycorrhizal fungi of Wisconsin's sandy soils, and a look at the Brussels Hill pit cave in Door County. Other articles explore the occurrence of sea lamprey in the lower Fox River, the recent invasion of white perch into the Fox River, and the history of the fishes of the Bois Brule River system. Together these many fascinating studies alert us to the changing natural environment of Wisconsin and to the ongoing parade of "visitors" who keep coming to our state, on their own (like the white perch and sea lamprey) or not on their own (like the jaguars in the zoo).

As I write this column in mid-August, I am preparing to teach an adult-education class next week at The Clearing, one of my favorite Wisconsin institutions, located in a spectacular natural setting on the bluffs above Ellison Bay. Currently an affiliate of the Wisconsin Academy, The Clearing was founded by the famous landscape architect and environmentalist Jens Jensen back in 1935 as a sort of outdoors "school of the soil." Over the years it has evolved into an independent association, supported by its many members and friends. During its summer residential program, The Clearing offers one-week courses on nature, the arts and humanities.

My course will be on "The Poetry and Message of the Psalms." Among the Psalms that will certainly feature prominently in our discussions will be Psalms 8 and 104. I expect some lively and interesting debate on whether or not these ancient religious poems have anything to say about current relationships between humanity and the natural environment. In my mind there is no doubt that, if the writers of these two psalms could be transported forward to our own day and could read the sort of selections contained in this current issue of *Transactions,* they would be confirmed anew in their appreciation for the world of nature, their sense of awe before its vast sweep and their feeling of interconnectedness with all its creatures.

Perhaps, if he could also be educated into the momentous ecological developments of our time—the Biology Department at UW Oshkosh teaches about "Ecosphere in Crisis"! — the poet of Psalm 8 would wish to reconsider or at least nuance the idea that humans are to exercise "dominion" over all other living things. Then again, if Hebrew Bible scholar James Limburg is on the right track in his reading of these two psalms, their ancient composers might ask us with deepened urgency, "Who cares for the earth?" "Who loves and treats gently this place that is home to so many relatives, human and non-human?"

It is clear to me, through my correspondence with our authors in this issue of *Transactions* and with the many fine reviewers who offered them valuable professional criticism and advice prior to publication, that there are many who undertake their scientific research precisely because they care for the earth. As a member of the Wisconsin Academy who has spent a lifetime of study and teaching in the humanities, I took great interest in reading these several articles devoted to the natural sciences and in discovering more about all the life around me in Wisconsin. As a biblical scholar, I found extra delight in playing off these articles against the appreciation for nature evident in some of the Psalms. I hope all of you, our readers, whether you lean more towards the sciences, arts or letters, will find similar enjoyment in reading the 1994 *Transactions.*

Now, as I look ahead to selecting manuscripts for future issues of *Transactions,* it is my pleasure to repeat the invitation for scholarly research and criticism on all aspects of science, arts and letters featuring the state and people of Wisconsin.

Bill Urbrock

The Wisconsin Academy of Sciences, Arts and Letters was chartered by the State Legislature on March 16, 1870, as a membership organization serving the people of Wisconsin. Its mission is to encourage investigation in the sciences, arts and letters and to disseminate information and share knowledge.

Jim Brozowski and Michael J. Day

Development of Brussels Hill Pit Cave, Door County, Wisconsin: Evidence from flowstone and sediment

Abstract *Brussels Hill Pit Cave is a joint-controlled vertical cave developed to a depth of 28 m in the Silurian-age Niagara Dolomite of the Door Peninsula in northeastern Wisconsin. Sediments and flowstones in the cave are post-glacial, with deposition beginning around the end of the Greatlakean substage, approximately 10,000 B.P. The cave sediments differ both physically and mineralogically from those on the surface. The cave is potentially older than the sediment infill and flowstones, possibly having formed in the late Cenozoic. Dating of cave flowstones using paleomagnetic and radioisotopic techniques suggests that initial deposition of these formations occurred approximately 11,000 B.P. From dissolution rate calculations (Palmer 1980) and paleomagnetic evidence we infer that the cave itself developed contemporaneously with sediment and flowstone deposition. The cave also contains significant early Holocene mammalian remains which are currently under investigation (Kox 1988).*

The Door County karst landscape is one of the few glaciated karst areas in the United States. Brussels Hill Pit Cave is a vertical cave formed along a dissolutionally widened joint in an outlier of the Niagara Dolostone Escarpment (Figs. 1a and 1b). Such caves are an integral part of the karst terrain of the Door Peninsula (Rosen 1984; Stieglitz 1984; Rosen et al. 1989; Johnson and Stieglitz 1990; Rosen and Day 1990). Recent paleontological work (Kox 1988; Robert Howe, pers. comm. 1992) has focused on a rich faunal suite within the cave. Previously excavated organic sediments from 28 m depth have been ^{14}C dated at 671 and 1820 B.P. (Howe, unpubl. data).

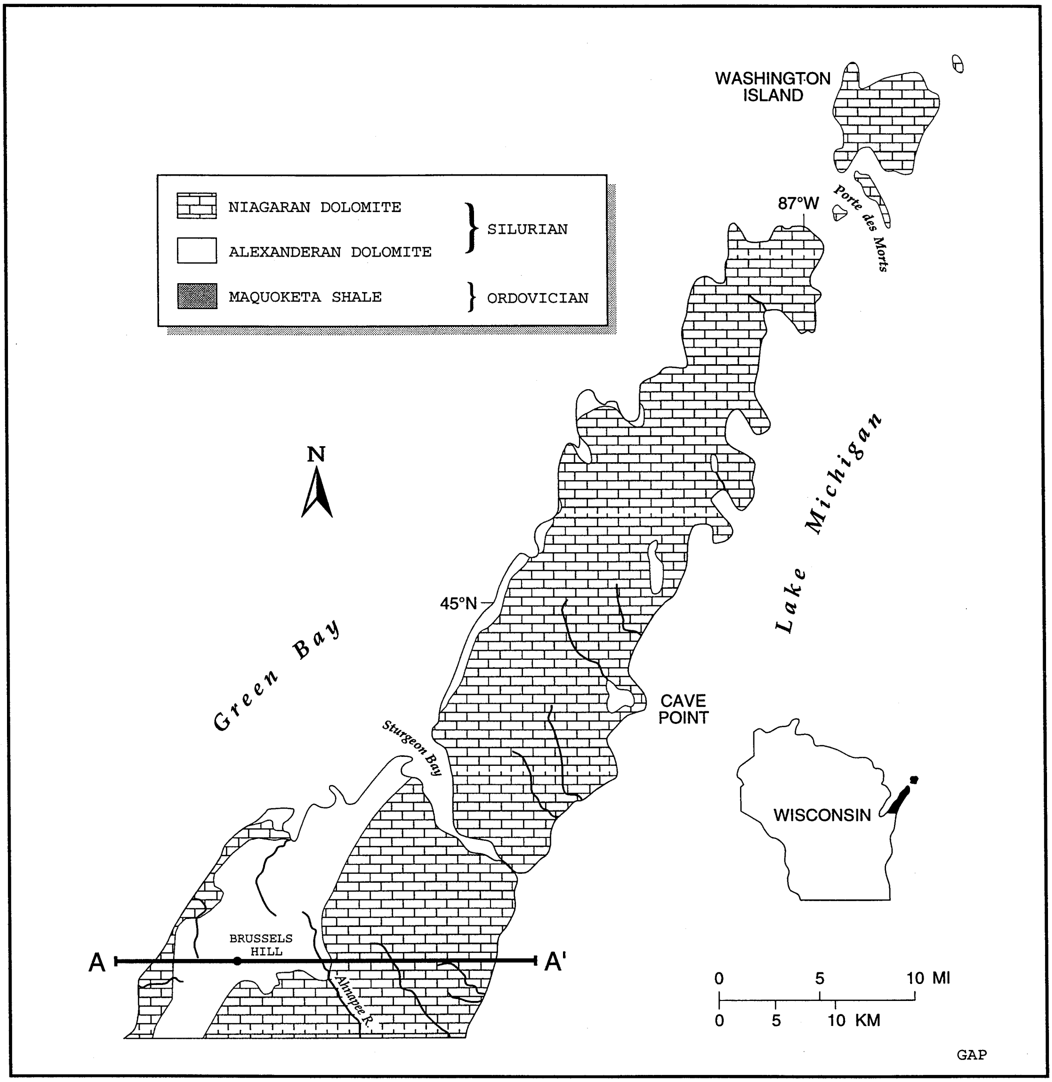

Fig. 1a. Geologic map of Door County (adapted from Sherrill 1978)

The primary objective of this study was to establish the chronology of sediment deposition within the cave. Determining the age of the flowstones and the source of the sediments would also provide information about the age and development of the cave itself.

Clastic sedimentary deposits and flowstone in caves are a tool for reconstructing the climatic history and geomorphic evolution of karst terrains (Milske et al. 1983). Lively (1983), Milske et al. (1983), and Lively et al. (1984) have presented flowstone and flowstone-sediment chronologies based on Uranium-series disequilibrium dating and have demonstrated that the flowstone deposition rate was significantly reduced during glacial periods in southeastern Minnesota. Gascoyne (1977) determined that, in general, speleothem deposits represent rela-

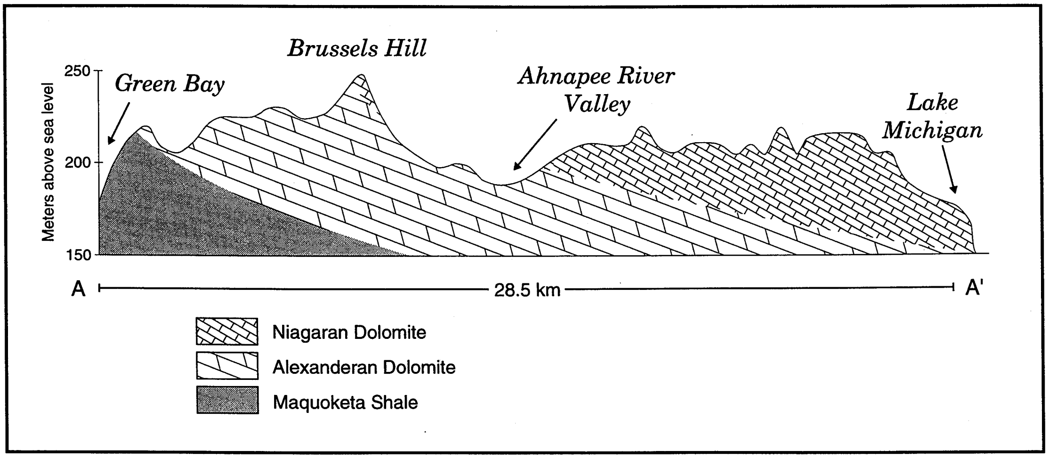

Fig. 1b. Generalized cross section of A – A'

tively warmer paleoclimatic periods, although speleothem growth may not always directly reflect surface conditions. Flowstone dating allows for a minimum estimation of cave age as the flowstone must be younger than the cave itself.

Cave formation age can also be estimated using carbonate dissolution rate calculations (Palmer 1980). Maximum rates under phreatic conditions are roughly 0.14 cm/yr or about 3 m every 1000 years. Extrapolating this rate calculation to vadose cave development, the 28 m depth of Brussels Hill Pit Cave suggests a maximum age of about 10,000 B.P., which coincides approximately with the deglaciation of the Door Peninsula.

The research presented here is used to test a developmental hypothesis for Brussels Hill Pit Cave and the associated sediment deposition. Based on Ford's (1977) four-part classification of glaciated karst areas, the cave is glaciokarstic or more specifically, karstiglacial, i.e., a karst process that has accentuated jointing which originally had resulted from glacial loading on the bedrock surface. Glaciokarst reflects the cumulative effects of karst formation and glacial activity (Ford 1977). We hypothesize that Brussels Hill Pit Cave is karstiglacial, based on the glacial history of the Door Peninsula (McCartney and Mickelson 1982). Cave formation commenced after glacial loading and unloading had accentuated bedrock jointing. Subsequent dissolution enlarged the joints and led to sedimentation followed by speleothem deposits.

Regional Geology and Geomorphology

The Door Peninsula is primarily an upland ridge with morphology controlled by the Niagaran Dolomite cuesta (Sherrill 1978). The bedrock geology of the Door Peninsula is outlined by Chamberlin (1877), Thwaites and Bertrand (1957), Klussendorf and Mikulic (1989), and Stieglitz (1984, 1989). The Niagaran Series is approximately 107 m thick and includes, from oldest to youngest, the Burnt Bluff Group, the Manistique Dolomite, and the Engadine Dolomite (Sherrill 1978; Stieglitz 1989). The rocks are mainly dolostones, thinly bedded in the lower formations and thinly to massively bedded in the upper formations. The rocks are fossiliferous, medium to coarse grained, and

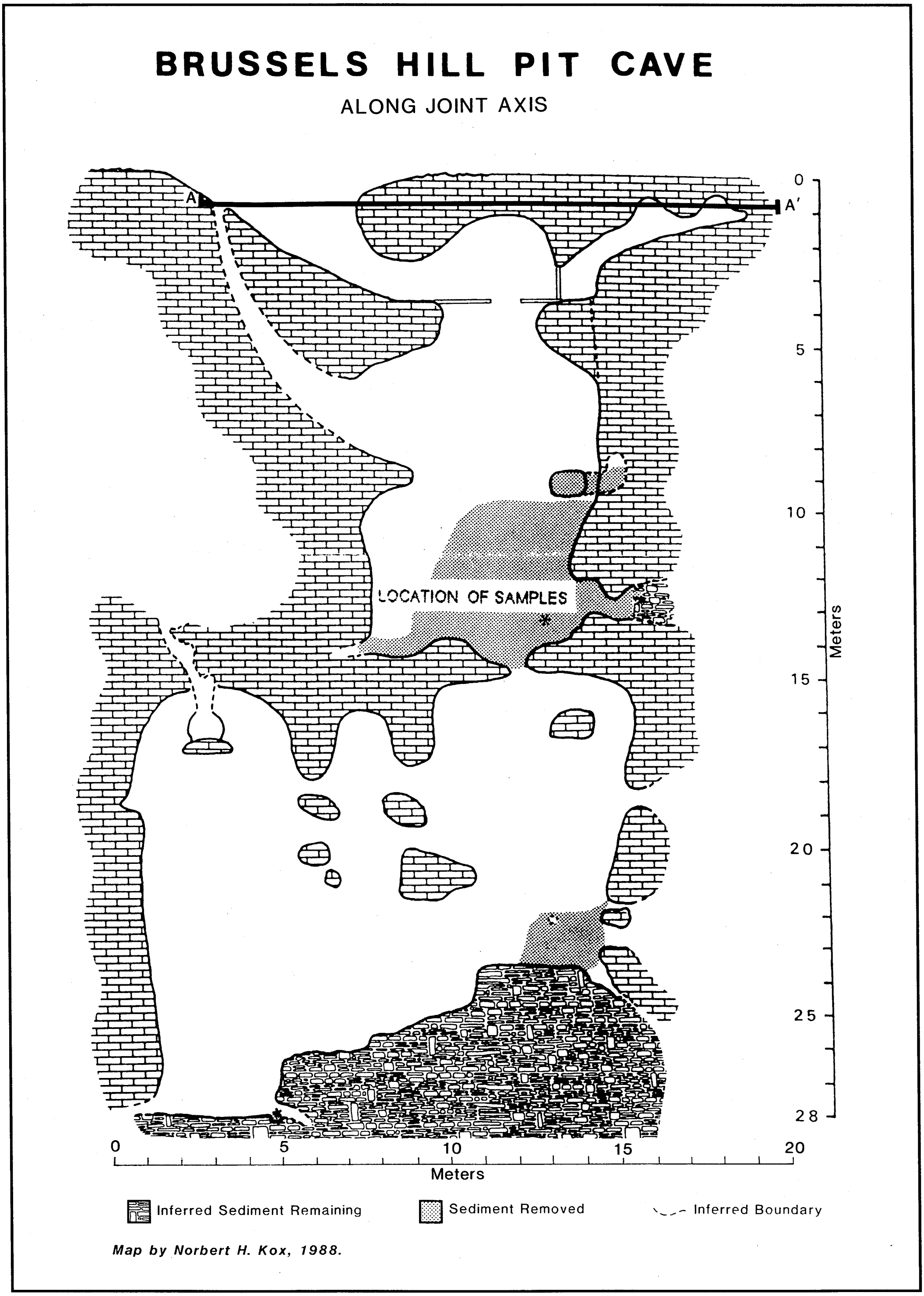

Fig. 2. Planar view of Brussels Hill Pit Cave

mostly buff gray colored. Dip of the bedrock is less than one degree to the southeast.

The Niagaran rocks form the Niagara Escarpment along the western edge of the Door Peninsula in Door County. West of the escarpment are several outliers of the Niagara Formation including Brussels Hill (Figs. 1a and 1b). Brussels Hill is a glaciated but erosionally resistant biohermal (reefal) structure; erosional resistance is attributed to the unstratified reef groundmass (Stieglitz 1984). The base of Brussels Hill is at 215 m; the summit is at 260 m.

Glaciation of the Door Peninsula occurred most recently during the Woodfordian (22,000 to 13,000 B.P.) and the Greatlakean (11,500 to 9500 B.P.) advances. These were separated by the Twocreekan interstadial between 13,000 and 11,500 B.P. (McCartney and Mickelson 1982). Deglaciation of the Door Peninsula coincided with the general retreat of the Lake Michigan and Green Bay lobes of the Laurentide Ice Sheet (Bryson et al. 1969; Hansel et al. 1985).

Although there were at least three major stages of Pleistocene glaciation in Wisconsin, it is not known specifically how frequently and for what duration the Door Peninsula was over-ridden by ice. Thus it is not known how many times karst processes on the Peninsula were disrupted.

Brussels Hill Pit Cave

The sinkhole entrance to Brussels Hill Pit Cave is at approximately 256 m above mean sea level and opens into a vertical drop of 28 m (Figs. 2 and 3). Brussels Hill Pit Cave is the deepest cave in Wisconsin and is developed along a joint oriented approximately 62 degrees east of north. Other prominent joint sets on Brussels Hill are at 25 and 155 degrees east of north (Rosen 1984). On the basis of altitude, location, and bedrock character, the cave is probably developed in the Manistique Dolomite.

In horizontal cross-section, the cave consists of two crude ellipsoids along the cave's vertical axis (Fig. 4). The three levels are apparently vadose, showing no evidence of phreatic development. Cave walls at the middle and lower levels are covered by flowstone drapery starting at bedding plane seepages 6 m below the cave entrance and extending to -28 m. Drapery samples for paleomagnetic determinations reported in this paper were collected at -15 m (Fig. 2). Prior to June 1986, only the cave above the -15 m level was known; excavations revealed a lower cave that descended to -28 m. Although some sediments have been removed from the lowest level, this study focuses on sediments at the -15 m level.

Paleontological analyses of the faunal remains from the -15 m level have identified short-tailed shrew (*Blarina brevicus*), common shrew (*Sorex* sp.), little brown bat (*Myotis licifugus*), white-tailed deer (*Odecoileus virginiana*), black bear (*Ursus americanus*), beaver (*Castor canadensis*), muskrat (*Ondatra zibethicus*) and otter (*Lutra canadensis*) (Howe, unpubl. data).

At -15 m, a flowstone ledge has formed over clastic sediments (Fig. 5). The flowstone consists of several layers of calcite mixed with bones, leaves, wood, fine organic material, and clasts of varying size and lithology. The ledge is approximately 15 cm thick and extends laterally for 150 cm to the southwest. It dips and pinches out near the lower room opening. The clastic sediments beneath the composite layer consist of layers of fine sand and silt about 25 cm thick. Based on their graded deposition and mixed igneous, metamorphic, and sedimentary mineralogy, the sediments are probably reworked surface glacial deposits. Samples for

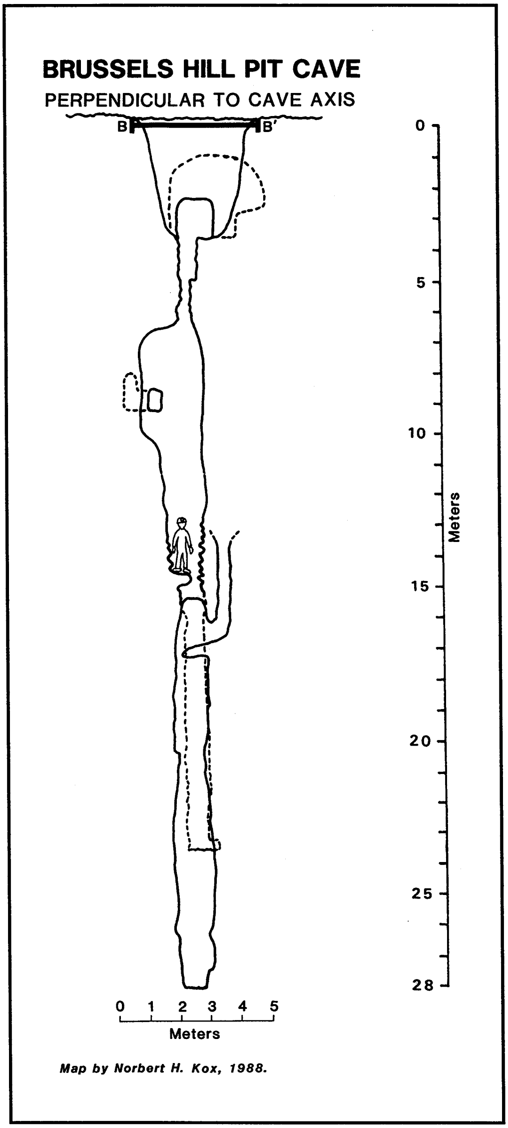

Fig. 3. Perpendicular cross-section of Brussels Hill Pit Cave

particle size and paleomagnetic analyses were removed from this relatively inorganic layer. Although some of the fine sandy and silty cave sediment is laminated, the laminae probably result from sediment reworking within the cave.

Below the fine sand layer is a variegated layer of coarse sand and fine gravel also about 25 cm thick (Fig. 5). This deposit includes several layers of coarse sediment cemented by crystalline calcite precipitate. The coarse basal sediments probably predate initial calcite deposition.

Beneath the cemented coarse sediment is a clay loam layer (Fig. 5) which contains several striated clasts and large (>30 cm) pieces of dolostone breakdown. Several of the clasts are well rounded, polished, and fluted indicating glacial transport.

In order to elucidate the relationship between surface soils and cave sediments, two soil pits approximately 15 m north and 15 m south of the cave entrance were opened, sampled, and analyzed. The Namur silt loam is the dominant regional soil (Link et al. 1978).

Methodology

Analytical Transmission Electron Microscopy (TEM) and Energy Dispersive X-Ray Analysis (EDXA) were used for visual and elemental analysis of the soils and sediments. Soil and cave clay mineralogy was determined using standard X-ray diffraction at the University of Wisconsin–Milwaukee. Soil particle size determination and pH measurement of the cave sediments and surface soils were performed using standard hydrometer methods and a calibrated laboratory pH probe.

Two flowstone cores were extracted for analysis from drapery on the north wall of the cave; each was physically abutting the Niagaran bedrock and retained a trace of dolostone patina when removed. Although there is no way to obtain perfect rotational alignment, every effort was made in the field and laboratory to maintain the closest possible alignment. Sediment cubes were obtained similarly.

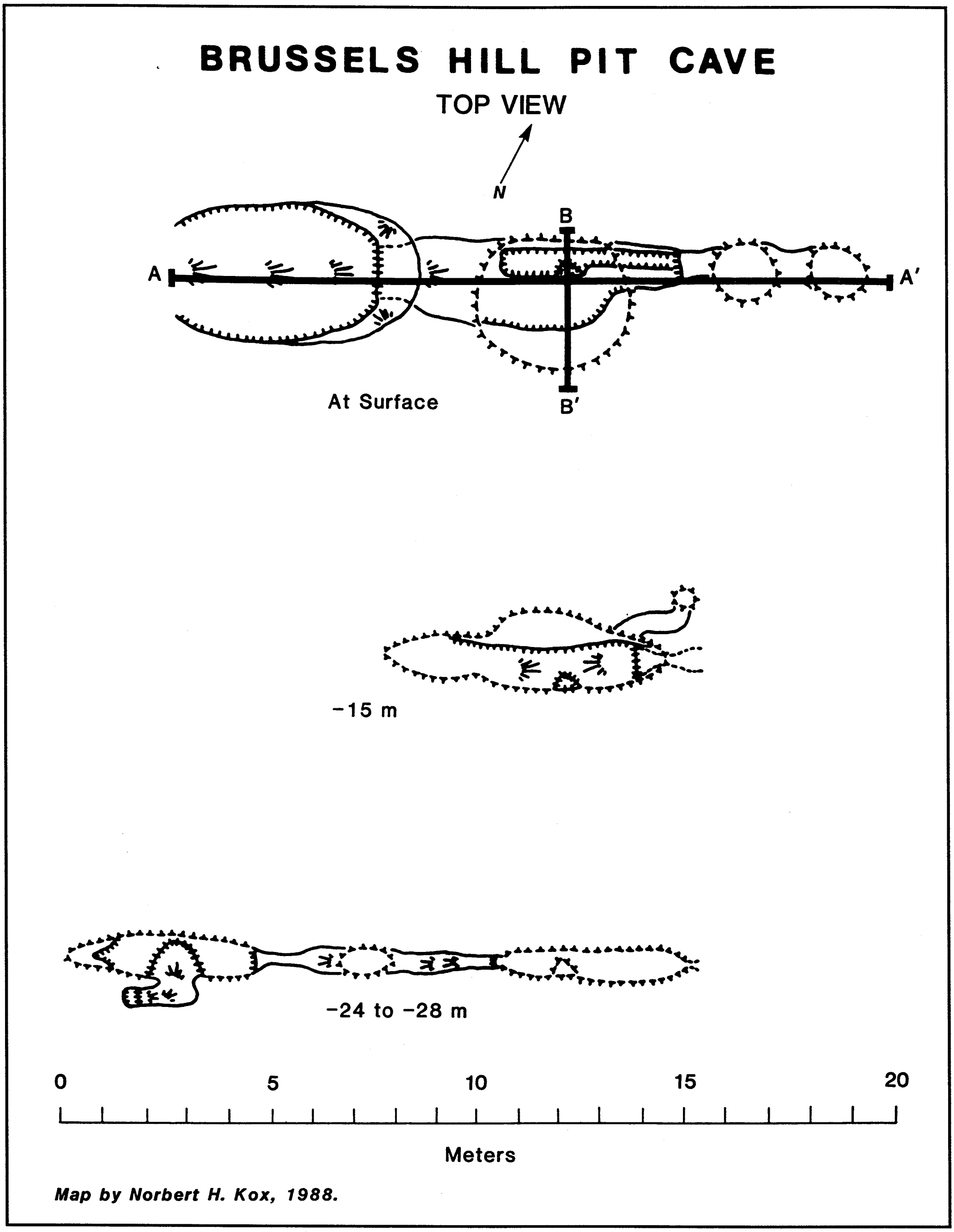

Fig. 4. Vertical top-view of Brussels Hill Pit Cave

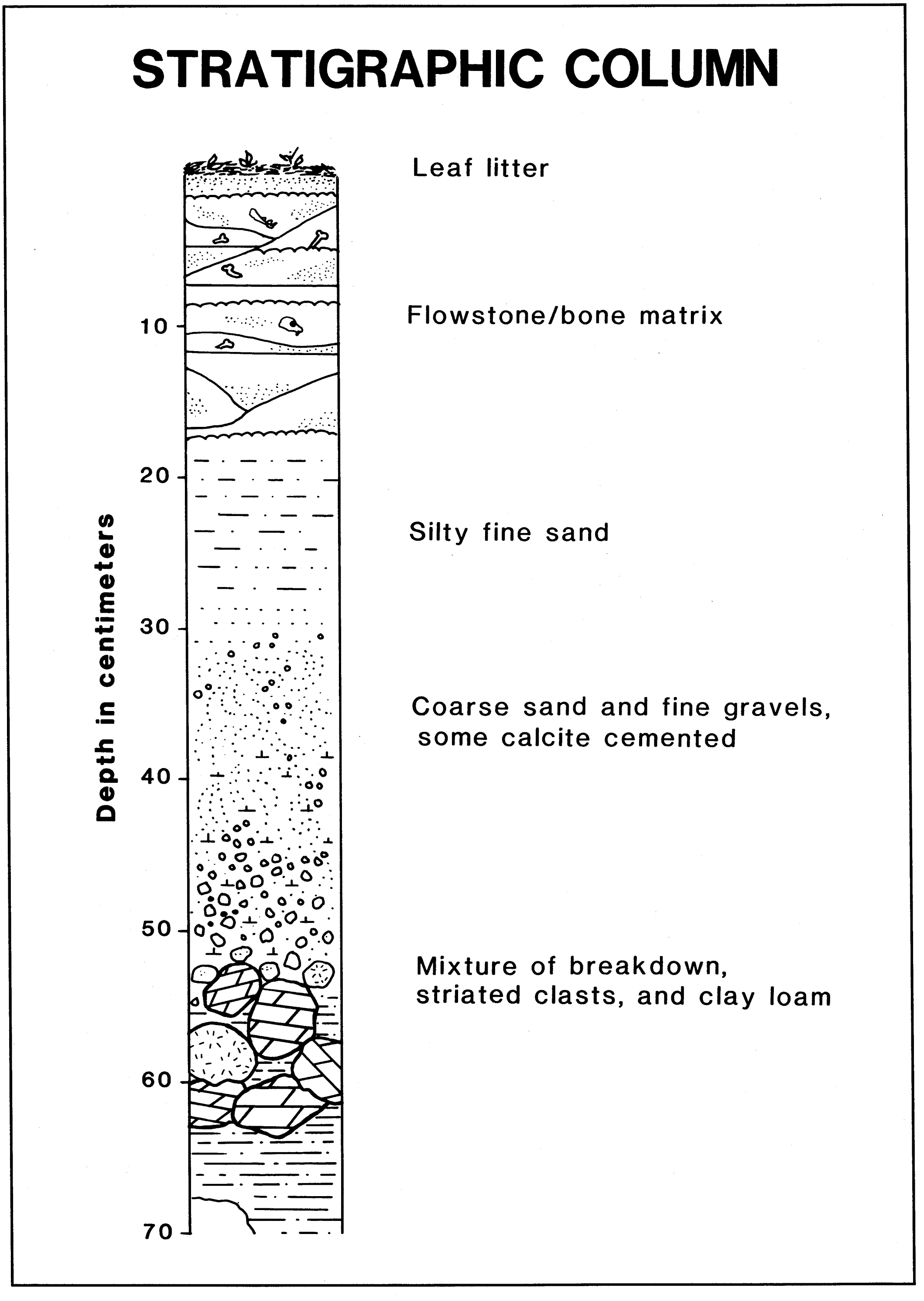

Fig. 5. Generalized stratigraphic column for the -15 m level

Paleomagnetic analysis was performed on a Superconducting Technology model C102 two-axis cryogenic magnetometer. The natural remnant magnetism (NRM) of each sample was measured first, then each was demagnetized using alternating fields stepwise up to 100 millitesla (25 to 1000 oersted). Sample remanence was measured after each demagnetization step; moment directions and intensities were calculated utilizing Fischer (1953) statistics. The paleomagnetic data for the cave were matched with a master curve generated from data sets for the Great Lakes area (Creer and Tucholka 1982; Kean and Klebold 1981).

Results

The Namur silt loam horizons are composed of the major elements aluminum, silicon, potassium, and iron, and the minor elements calcium, magnesium, and zinc. Clay minerals include illite, smectite, and chlorite. Soils sampled near the bedrock contact contain a high percentage of sand-sized grains (Fig. 6).

The sample from 40 to 56 cm in Soil Pit 2 contained smectite (montmorillonite) clays. Smectite forms in neutral to alkaline environment containing relatively high concentrations of calcium and magnesium (Brady 1974; Birkeland 1984). The Niagaran Dolomite, $CaMg(CO_3)^2$, has sufficient calcium and magnesium for smectite clay formation.

Cave clay loam analyses indicate the presence of silicon, iron, potassium, aluminum, calcium, magnesium, and zinc. Minerals include calcite, dolomite, quartz, and the clay minerals kaolinite and illite. Kaolinite is of interest because it forms primarily by the complete weathering of alkaline feldspars, through hydration at low pH (Klein and Hurlbut 1985). Generally, illites are the most common clay minerals in caves (Bull 1983; Sweeting 1973); they are formed by the loss of potassium and possibly aluminum from the mineral layers through hydration.

The Namur soil pHs vary from slightly acidic to neutral, pH 5.0 to 7.0, while the cave clay-loam is relatively alkaline, at pH 8.3. This suggests that the solvent capacity of percolating surface water, in contrast to Barden (1980), is not effectively neutralized by carbonate clasts, at least in this location. The pH of each soil horizon is moderated by proximity to the dolostone bedrock (Fig. 7). Contemporary dissolution may thus be expected on dolomitic bedrock or within caves beneath the Namur silt loam. No glacial striae were observed at either of the test pit soil/bedrock contacts beneath the Namur silt loam, and no striae were detected on any bedrock exposures examined in the immediate area. A sample of seepage water from the -15 m level had a hardness of 130 ppm (mg/L) total calcium and magnesium.

Paleomagnetic analysis results were correlated with the type-curve data provided by Creer and Tucholka (1982). Flowstone core inclination and declination values were 58° and -60°, respectively, indicating deposition between approximately 9830 and 11,260 B.P. For the cores, inclination correlations occur about 9700, 10,200, and 11,000 B.P. and declination correlations between 9000 and 11,260 B.P. (Figs. 8 and 9). Sediment cube correlations (declination and inclination values of 13° and 70°, respectively) occur several times for declination at about 7000, 9000, and 10,000 B.P.; inclination correlations occur at about 7000, 9000, and 9800 B.P.

Flowstone samples submitted to the Minnesota Geological Survey for U-series dating proved too porous and chalky for a reliable analysis. During a previous flowstone dating attempt the isotopic results showed evidence of post-depositional alteration in the calcite. The uranium concentration was very

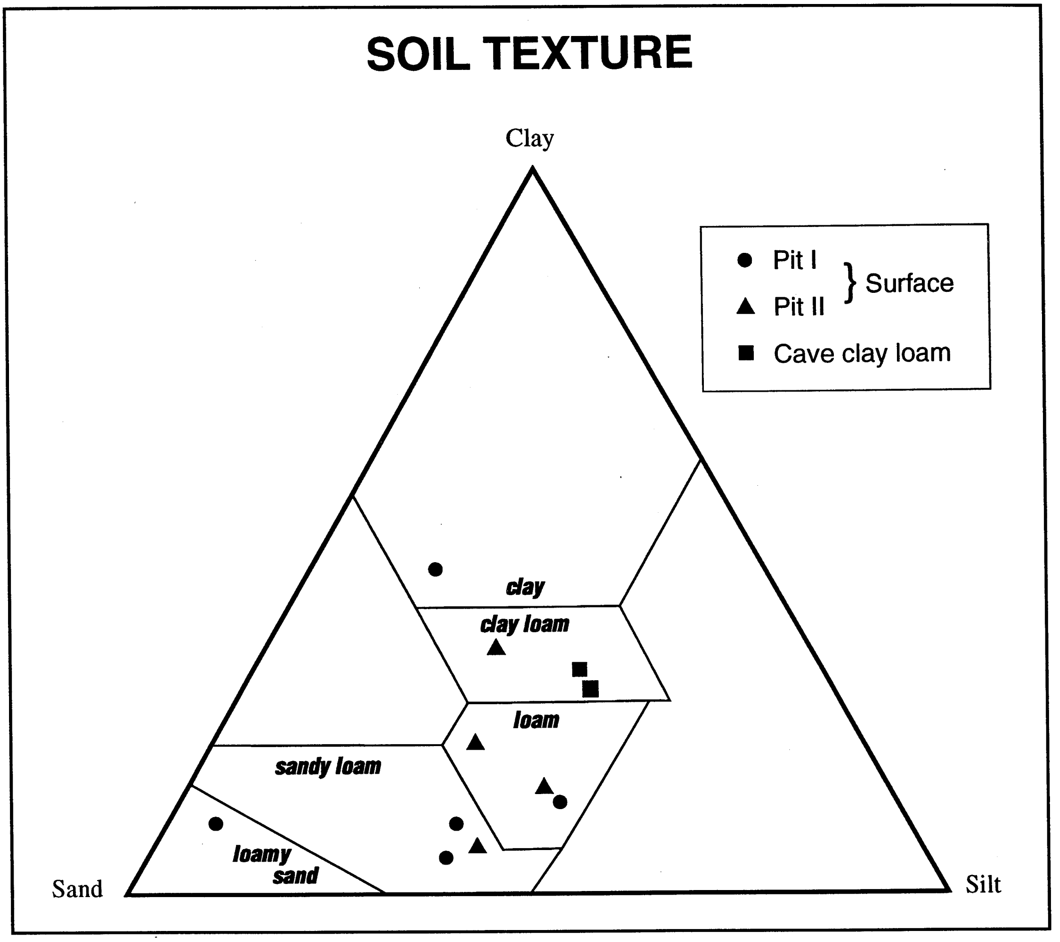

Fig. 6. Soil textural triangle

low (0.08 ppm) and the $^{230}Th/^{234}U$ activity ratio was greater than unity. Chemical recovery of Th from the sample was less than 5% (Richard Lively, pers. comm. 1992).

Discussion

The area around Brussels Hill Pit Cave is a glaciated karst terrain in which karstiglacial or post-glacial development of karst, sediment, and soil is related to the effects of Wisconsinan glaciation. The cave serves as a depository for allochthanous organic and mineral debris brought in directly through the cave opening and indirectly through percolation.

There are few mineralogical similarities between the surface soil horizons and the cave clay-loam; minerals notably present in the Namur soils and very limited in the cave clay-loam are zinc and iron. Elements present in the cave clay-loam and not in the soil are calcium and magnesium. The magnesium and calcium in the cave clay loam are probably derived by dolomite dissolution. Chemical analyses of the dolostones approximates a 1:1 (Ca:Mg) ratio (Johnson and Stieglitz 1990). Although the specific

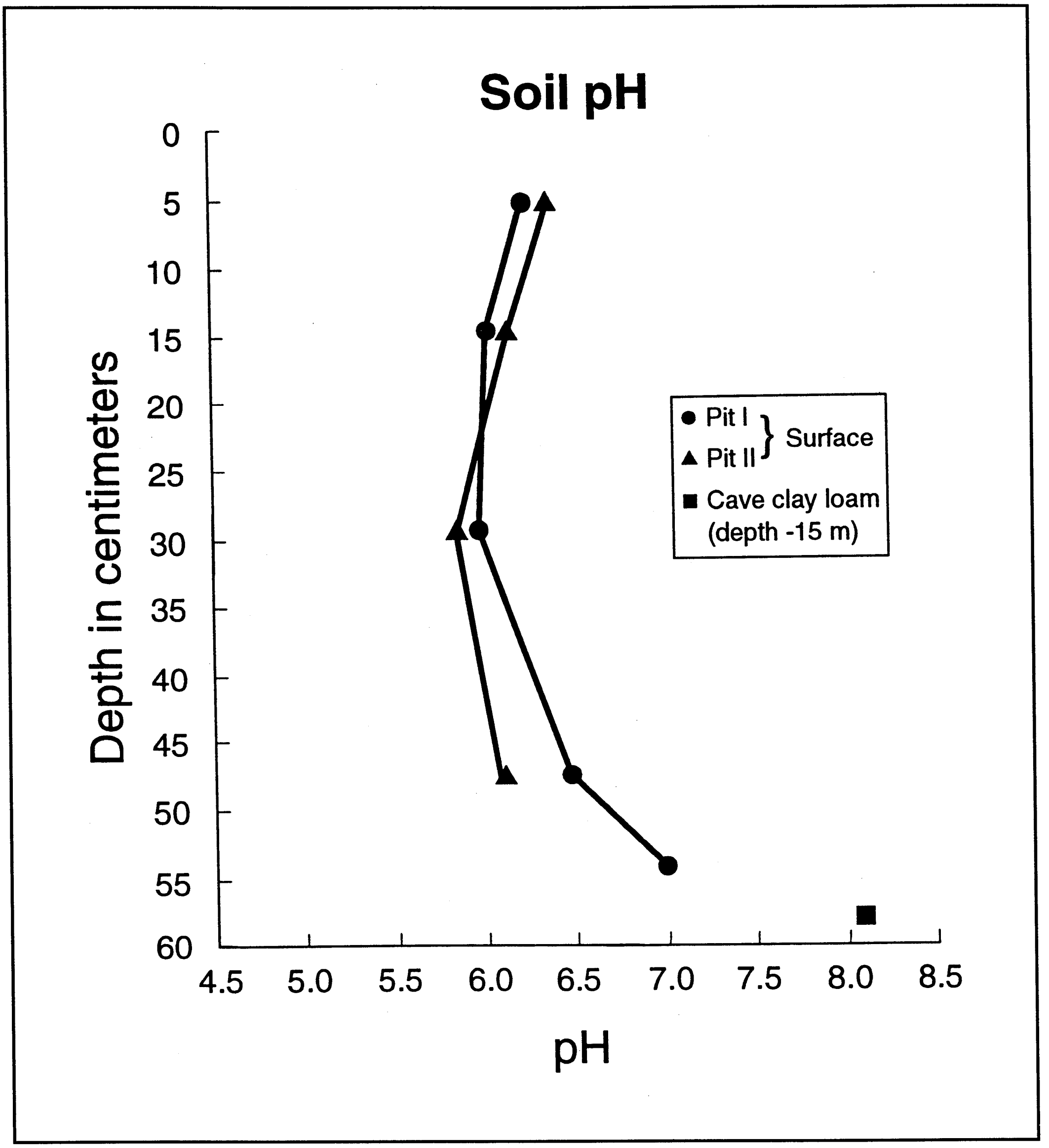

Fig. 7. Soil pH values

mechanism of cave clay deposition is not known, it may predate the surface soil formation, having been deposited either as loess or in a slurry during deglaciation.

Mineralogically, illite in the cave and smectite at the surface are not unexpected. Illite is the dominant clay mineral in unweathered till and loess as well as the most common clay mineral in caves (Bull 1983; Sweeting 1973); it forms under leaching conditions with high K concentrations. Small amounts of kaolinite and smectite may also appear (Grim 1968). Smectite formation may be related to tundra or boreal climates in the Door Peninsula during glacial recession.

Kaolinite and illite genesis are dissimilar, the former being formed under acidic conditions and the latter under alkaline conditions. Kaolinite formation could not have occurred in the cave under current pH conditions. The kaolinite may have been eluviated from the overlying Namur soil where it developed at a lower pH. Alternatively, kaolinite may have developed within an earlier pre–Late Wisconsinan soil profile, or it may have been derived from a nearby bog, marsh, or wetland. Illite probably developed *in situ* by the alteration of alkaline feldspar or mica under alkaline conditions.

In terms of particle-size distribution, only the lowest horizon of Soil Pit 2 is similar to the cave clay loam (Fig. 6). The increase in grain size with depth in the lowest horizon of Soil Pit 1 may be attributed to mechanical illuviation but is more likely to reflect granular material incorporated from dissolution of the dolomitic bedrock.

Since the cave clay loam is near the bottom of the cave sediment profile, it was either deposited before the rest of the sediment in the profile or it represents fines eluviated from overlying cave sediments. The relocation of coarse sand and fine gravel fractions probably occurred prior to the flowstone deposition. The origin of the coarse sand and fine gravel has not been determined, but these may have been introduced during deglaciation. Soil particles may have moved from the surface into the cave along joints and other fractures, with the joint width acting as a natural sieve, screening out larger particles. As Rosen (1984) states, the thin surficial deposits facilitate seepage concentration at or along joints and joint intersections. Karstic development is accelerated along the joints as is allochthanous sediment movement into the subsurface.

Based on paleomagnetic results, the flowstones were determined to have formed between approximately 9000 and 11,000 B.P. (Figs. 8 and 9). Although the established date is relative, there is a clear correlation with the results of previous Great Lakes paleolimnetic studies (Vitorello and Van der Voo 1977; Creer and Tucholka 1982) and the deglaciation of the Door Peninsula (Bryson et al. 1969).

Upper portions of the flowstone incorporate numerous bones, while the wall flowstones contain either burned or chemically reduced wood fragments. Howe (pers. comm. 1992) suggests that the wood remnants may be from the 1871 Peshtigo Fire which burned portions of the Door Peninsula. Because the flowstone formation is stratigraphically superior to the mineral sediments, it is assumed that the latter were deposited prior to flowstone deposition, during or immediately after glacial retreat. It is not known whether the coarse sand and fine gravel are an initial deposit or the result of sediment reworking. The intrinsic variety and morphology of the granular cave sediments indicate reworking and relocation by surface runoff. Whether this was because of historical near-ice meltwater run-off or contemporaneous temperate run-off is unclear; however, the lack of organic material and the flowstone shelf with subordinate striated clasts strongly suggest the former. As the flowstone is resting on the sediment and appears to have remained physically and stratigraphically stable and is probably less than 10,000 years old, the underlying sediment tentatively correlates to the Greatlakean substage between 9000 and 10,000 B.P. Similar stratigraphic sedimentary profiles have been described in Mystery Cave in southeastern Minnesota (Milske et al. 1983).

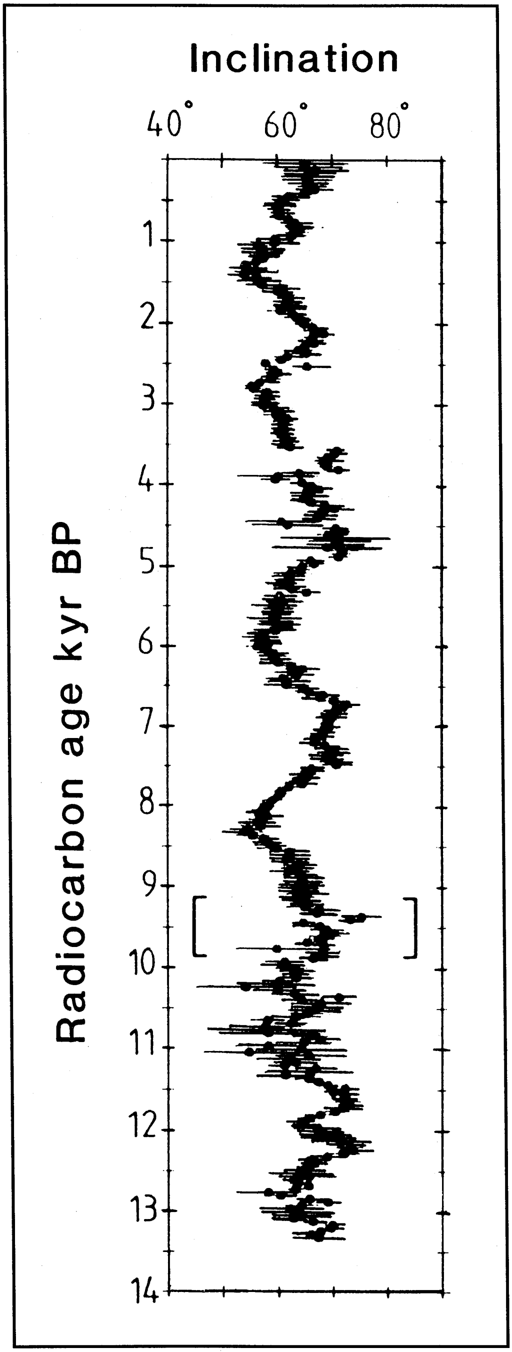

Fig. 8. Inclination type curve for east-central North America. Brackets indicate inclination value of 58° for flowstone cores which correlates to 9700 years B.P. (Modified from Creer and Tucholka 1982)

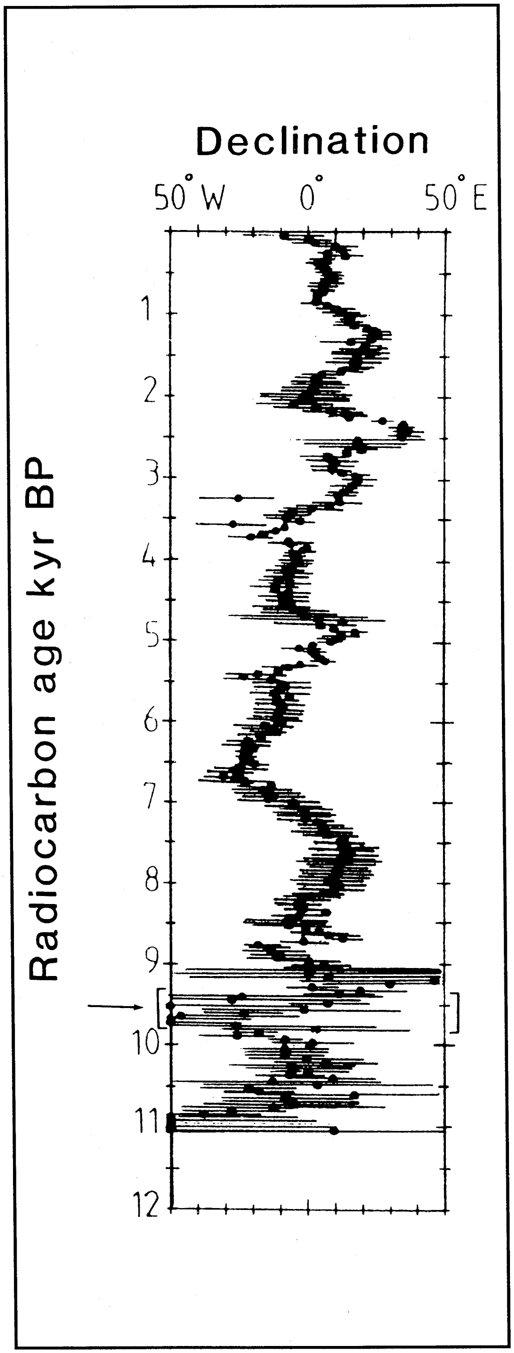

Fig. 9. Declination type curve for east-central North America. Brackets indicate inclination value of 58° for flowstone cores which correlates to 9700 years BP. (Modified from Creer and Tucholka 1982)

Conclusion

Based on our interpretation and following Ford's (1977) classification, Brussels Hill is a karstiglacial topographic feature. We further interpret the topographic morphology of the area as glacial in origin with subsequent post-glacial karstic modification. Jennings (1985, 239) defines karstiglacial forms as "forms thought to be virtually entirely glacial but [upon which] karst drainage characteristics have been superimposed." Brussels Hill may be a relict karstiglacial feature, having been formed during or prior to Wisconsinan glaciation with subsequent formation of the pit cave during interglacial conditions.

Interglacial or post-glacial warming produced meltwater which was responsible for sediment transport into the cave. Increased water flow would have enhanced dissolution of the Niagaran Dolomite. Flowstone and sediment ages in this report correlate with the general time of Wisconsinan deglaciation of the Door Peninsula but do not themselves reveal the initial date of cave formation.

Brussels Hill Pit Cave sediments are of post-glacial origin based on relative age determinations. Granular sediment in the cave differs in texture, pH, and mineralogy from surface materials. The cave itself pre-dates the sediment fill, and the available evidence and dissolution-rate calculations from Palmer (1980) indicate that cave development and sediment deposition could have begun at the end of the Greatlakean substage, about 10,000 B.P. Further research into the history of the lower cave levels will continue at the conclusion of the faunal studies.

Brussels Hill Pit Cave contains a post-glacial sediment sequence covered by later sediments and organic material of Recent (Holocene) age. The coarse sands and gravel may have been deposited during the initial stages of glacial recession when water was available to transport the coarser fractions; as water volume decreased with ice retreat, transport potential also decreased, depositing only finer sands and silts. Collapse of the cave sinkhole entrance probably occurred at a relatively recent time.

Sediment variety poses interesting questions about sediment deposition and mineralogical formation; physical and chemical alteration of minerals through changes in water and soil pH and possibly climatic transition could be examined further as could individual sediment particle mineralogy.

The record obtained from Brussels Hill Pit Cave assists in the analysis of Wisconsin's pre-settlement faunal assemblages (Howe, pers. comm. 1992) and also provides a valuable record of post-glacial geomophological events in northeastern Wisconsin.

Acknowledgments

Jim Brozowski wishes to thank the review editors for their insight and constructive comments. Thanks to Drs. W. F. Kean and B. E. Brown, Dept. of Geoscience, UW–Milwaukee, for their assistance through the various analytical stages. Special thanks to Ms. C. A. Syrrakos for skillful cartographic and diagram preparation.

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Philip A. Cochran

Occurrence and significance of sea lamprey (Petromyzon marinus) *in the lower Fox River, Wisconsin*

Abstract *The Rapide Croche lock on the lower Fox River was sealed in the winter of 1987–1988 to prevent upstream passage of spawning-phase sea lamprey* (Petromyzon marinus) *into the Lake Winnebago watershed. This action was taken because of concern that improvements in river water quality made colonization by lampreys inevitable, even though sea lampreys had not been collected in the Fox River prior to closure of the lock. The collection of sea lampreys in the Fox River in 1991, 1992, and 1993 substantiates the initial concerns and justifies the closure of the Rapide Croche lock.*

The sea lamprey (*Petromyzon marinus*) had a devastating impact on fish assemblages in the Great Lakes (Smith 1971; Smith and Tibbles 1980; Coble et al. 1990) prior to initiation of effective chemical control in the early 1960s. Sea lamprey control remains largely predicated on chemical treatment of tributaries inhabited by ammocoetes, but the process is costly and labor intensive. As control costs rise, it becomes increasingly desirable to minimize the number and length of streams that must be chemically treated.

Sea lampreys typically spawn in water of relatively high quality. Although they have been known to ascend polluted rivers to spawn in cleaner tributaries, there are known cases in which lampreys have apparently been inhibited by poor water quality from ascending polluted rivers. Ironically, one result of pollution abatement and improved water quality has been an increase in the number of streams used by spawning-phase sea lampreys. For example, sea lampreys colonized the Peshtigo River following pollution abatement in the early

1970s, leading to increased lamprey abundance in Green Bay (Moore and Lychwick 1980).

In the latter half of the 1970s, fisheries biologists in the Wisconsin Department of Natural Resources (DNR) and elsewhere became concerned about the possibility of sea lampreys ascending the Fox River from Green Bay (Kernen 1979; Smith and Tibbles 1980). Although the river was historically subject to severe pollution, by the 1980s water quality had improved to the point that a walleye (*Stizostedion vitreum*) fishery was reestablished below the De Pere dam, spawning-phase silver lampreys (*Ichthyomyzon unicuspis*) ascended the Fox River from Green Bay each year (Cochran and Marks, in press), and several species of salmonids were present in the lower river during the spring when water temperatures were favorable. Concerns about sea lampreys in the Fox River reflect several possible scenarios, which are not mutually exclusive. First, if sea lampreys gained access to the extensive high quality tributary systems in the Fox River drainage above Lake Winnebago (e.g., the Wolf and Embarrass rivers), spawning would probably be successful. Lampreys produced in these tributaries might pose a threat not only to fisheries in Green Bay and Lake Michigan, but also to Lake Winnebago fisheries previously unexposed to sea lampreys. The sea lamprey's proclivity for size-selective attack (Farmer and Beamish 1973; Cochran 1985) would make Lake Winnebago's unique and valuable lake sturgeon (*Acipenser fulvescens*) population a likely first target. Second, sea lampreys conceivably might spawn in some reaches of the Fox River proper, much as they are known to spawn in the St. Mary's River between lakes Superior and Huron (Smith and Tibbles 1980). Regardless of where it occurred, reproduction in the Fox River system would greatly increase the cost and difficulty of chemical control, or, if unchecked, endanger valuable fisheries.

In 1987, the Wisconsin DNR recommended that a lock on the lower Fox River be sealed and the corresponding dam modified to prevent upstream migration by sea lampreys. This proposal drew protests, primarily from pleasure boaters accustomed to traveling the Fox River between Lake Winnebago and Green Bay. Nevertheless, the recommendation was reaffirmed by the Sea Lamprey Study Committee appointed by the governor of Wisconsin (1988), and the Rapide Croche lock at the third dam upstream from Green Bay was sealed during the winter of 1987–1988.

All of the previous developments occurred before any sea lampreys were collected in the Fox River proper. Beginning in 1979, the U.S. Fish and Wildlife Service had sponsored the placement and monitoring of a sea lamprey assessment trap below the De Pere dam each spring during the lamprey spawning season, but no sea lampreys had ever been collected in the trap. Critics of the closure of the Rapide Croche lock pointed to the lack of evidence that sea lampreys had ever entered the river. Proponents of the closure argued that sea lampreys had been taken in Green Bay at the mouth of the Fox River and that by the time sea lampreys were detected in the river itself, it might be too late to prevent their spread into the Lake Winnebago system.

In light of the controversy surrounding the closure of the Rapide Croche lock, the subsequent capture of sea lampreys in the Fox River is noteworthy. The purpose of this report is to describe the lamprey collections and discuss their significance. Because of inaccuracies in accounts presented through the popular media, it is important that an accurate record be provided.

Methods

A portable sea lamprey assessment trap (Schuldt and Heinrich 1982) has been set each year since 1979 below the east end of the De Pere dam, approximately 12 km upstream from Green Bay. Additionally, a trap was set in 1988 and 1989 in the Osen millrace just east of the De Pere lock. Traps were checked five days per week from early April to mid-June. Measurements of total length (TL) and body mass (BM) reported here were collected from live animals anesthetized with tricaine methanesulfonate or from dead specimens prior to preservation.

Results and discussion

Lamprey assessment trapping and other fish collecting during the years 1979–1990 yielded no sea lampreys, but five individuals were collected from 1991 through 1993. In 1991, the trap was first lifted on April 5 after being set the previous day, and it contained an adult male sea lamprey (University of Wisconsin–Madison Zoology Museum, UWZM 9975; TL – 587 mm, BM - 365 g). Water temperature was 5°C. Subsequently in 1991, two additional specimens were collected by the Wisconsin DNR in fyke nets set in the Fox River between the De Pere dam and Green Bay. In 1992, an adult female sea lamprey (TL – 600 mm, BM – 505 g) was trapped on April 6 at a water temperature of 5°C. No sea lampreys were trapped in 1993, but the Wisconsin DNR, while electrofishing below the De Pere dam on October 12, collected a lake trout (*Salvelinus namaycush*) bearing a parasitic-phase individual (TL – 353 mm, BM – 84 g).

The relatively large sizes of the lampreys captured in the trap is typical of sea lampreys collected in tributaries to Green Bay (Johnson 1982). However, collection of upstream migrants in early April is relatively unusual in northeastern Wisconsin. For example, during 1987–1989, the first sea lampreys were captured in assessment traps in the East Twin River, Manitowoc County, on April 23, May 7, and April 26. Johnson (1982) trapped most of the lampreys he collected in the Peshtigo River during the period May 16–31. Sea lampreys began entering the Peshtigo River traps after the water temperature reached 10°C, and peak catches occurred between 15.6°C and 21.1°C.

Contrary to certain accounts in the popular media, sea lampreys in the lower Fox River do not constitute a threat to fisheries in Lake Winnebago at this time, because the Rapide Croche lock remains sealed to prevent their upstream passage. However, sentiment to reopen the Fox River waterway to unimpeded boat traffic persists in some quarters, and documentation that sea lampreys occur in the Fox River helps legitimize opposition to that sentiment. Any future arrangement for boat passage at the Rapide Croche dam must involve a boat lift or some other terrestrial transport. This will prevent upstream passage not only by sea lamprey, but also by white perch (*Morone americana*), an exotic species that was first captured in Green Bay and the lower Fox River in 1988 (Cochran and Hesse 1994). Closure of the Rapide Croche lock may fortuitously have prevented the white perch from gaining access to Lake Winnebago.

It remains to be seen whether increasing numbers of sea lamprey will ascend the lower Fox River during subsequent spawning seasons. Whether such an occurrence is biologically significant depends on whether spawning is successful and whether the burrowing ammocoetes can survive in the lower river or Green Bay for the duration of the larval phase (roughly four to five years). It has been suggested that walleye reproduction in the lower Fox River is limited by the availability of chemically suitable substrate (Auer and Auer 1990), and it may be tempting to extend that conclusion to sea lamprey. However, although Auer and Auer (1990) cited a lack of evidence of natural recruitment by walleye in the Fox River, juvenile walleye of yearling size are collected with regularity in the sea lamprey trap in De Pere, despite the fact that the Wisconsin DNR discontinued stocking after 1984 (Schneider et al. 1991). Moreover, the recent occurrence of adult *Hexagenia bilineata* mayflies along the Fox River at the De Pere dam (Cochran 1992) indicates that conditions at the sediment-water interface have improved to the point that *Hexagenia* naiads can once more complete their development in a microhabitat similar to that used by sea lamprey ammocoetes.

At this time, the significance of sea lampreys in the lower Fox River is primarily symbolic. They are symbolic, for example, of the improvements in water quality that first permitted them to become an issue. More importantly, they provide an historical footnote to a case in which foresight and proactive measures prevented the contamination of a watershed by exotic species. Such cases are all too rare and warrant documentation.

Acknowledgments

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Philip A. Cochran and Peter J. Hesse

Observations on the white perch (Morone americana) *early in its invasion of Wisconsin*

Abstract *White perch* (Morone americana) *were first reported in the Green Bay/ Fox River system in Wisconsin in 1988. Total spring catches in sea lamprey assessment traps below the De Pere dam increased until 1990, decreased in 1991, and then increased sharply in 1992 and 1993. These collections are believed to represent at least in part the result of upstream movements related to spawning. White perch were not trapped in large numbers each spring until water temperature exceeded 17–18° C, and males were collected on average slightly earlier than females. Several age classes were present among fish captured as early as 1989. Growth rates were relatively high and were comparable to those in other locations in the Great Lakes where populations are expanding. Growth declined, however, with increasing age. Relationships between weight and length were similar between the two sexes. Although the spread of the white perch up the Fox River appears to have been blocked by the sealing of the Rapide Croche lock in 1988, more information is needed to assess its impact in the lower Fox River and Green Bay, and care must be taken to minimize its chances for invading Wisconsin's inland waters.*

The white perch (*Morone americana*) invaded the Great Lakes from the Atlantic Coast in the 1940s and 1950s by way of the Erie and Welland canals (Johnson and Evans 1990). It was first identified in the Lake Michigan drainage in the lower Fox River of Wisconsin in May 1988 (Meyers 1988), and in September 1988, it was collected in Belmont Harbor in Chicago (Savitz et al. 1989). Collections from inland waters in Illinois (Blodgett 1993), including the Illinois River, indicate that it has spread from Lake Michigan through the Upper Illinois Waterway, which connects the Great Lakes and the Mississippi River drainages.

Concern about the colonization of Wisconsin waters by white perch stems from (1) the possibility for it to compete with more desirable native species (Schaeffer and Margraf 1986a), (2) its potential impact as a predator on the eggs of other species (Schaeffer and Margraf 1987), and (3) the potential for it to interbreed with the white bass (*M. chrysops*). In this paper we present data on the biology of the white perch early in its invasion of Wisconsin waters. Our results can serve as a basis for comparison with future data collected after the white perch presumably becomes fully established. Our experience also provides insight into the effectiveness of programs to monitor the spread of other exotic species, such as the sea lamprey (*Petromyzon marinus*).

Methods

White perch were collected with other fishes in portable sea lamprey assessment traps (Schuldt and Heinrich 1982) set below the De Pere dam on the Fox River, Brown County, Wisconsin, 12 km upstream from Green Bay. In 1988 and 1989, one trap was set below the eastern end of the dam spillway and another below a small spillway associated with a hydroelectric generator in a building east of the lock channel. The latter spillway is situated at the head of a millrace which enters the Fox River below the lock channel. Data from the two traps were pooled. From 1990 to 1993, a single trap below the dam spillway was monitored. Trapping was conducted for ten weeks from early April to mid-June in all years according to a protocol dictated by contract with the U.S. Fish and Wildlife Service. In addition, we trapped during the periods October 4–11, 1992, February 8–13, 1993, and June 12–October 29, 1993. Traps were emptied five days per week at intervals of no greater than 48 hours. Water temperature was recorded each time the traps were emptied. During the years 1989–1991, white perch were enumerated and, on most days, taken to the laboratory to be weighed and sexed (1990 only) and measured for total length (TL). In 1989 and 1990, scale samples for age determination by the junior author were collected from the upper left side between the lateral line and the second and third dorsal fin spines.

We occasionally collected fishes in the Fox River upstream from the De Pere dam by electrofishing with a boat-mounted generator (pulsed DC current). Samples were collected in 1988, 1989, 1992, and 1993, most often in the vicinity of the St. Norbert College campus.

Voucher specimens (UWZM 9726) have been deposited in the University of Wisconsin–Madison Zoology Museum.

Results

White perch were first detected in the Fox River in 1988 during the interval that the sea lamprey traps were operated (Meyers 1988), but no white perch were collected in the traps that year. Twelve individuals were captured in the two traps monitored in 1989 (Table 1). During the period 1990 to 1993, when a single trap was operated, total spring catch ranged from a low of 21 in 1991 to a high of 1196 in 1992 (Table 1). In October 1992, six trap days yielded a total of 20 white perch (22% of the combined catch of all species). No white perch were collected during four trap days in February 1993.

In most years trapping ended in mid-June, but in 1993, it was extended through the summer and into autumn. The high catches of late May and early June (Fig. 1) declined through late June and July. Monthly totals for June and July were 465 and 60, respec-

Table 1. Total yearly trap catch of white perch, percentage of total catch for all fish combined, mean date of capture, and mean temperature of capture. Means are followed by standard errors in parentheses.

Year	*Number of White Perch*	*Percentage of Total Catch*	*Mean Date of Capture*	*Mean Temperature of Capture (°C)*
1988	0	0	—	—
1989	12	0.3	May 27 (1.7)	19.0 (0.2)
1990	189	6.9	May 9 (0.5)	16.8 (0.2)
1991	21	0.7	May 30 (2.0)	19.8 (0.7)
1992	1196	17.7	May 28 (0.3)	18.4 (0.1)
1993	823	24.3	May 25 (0.4)	15.4 (0.1)

tively. No white perch were collected from August 1 through October 29.

Differences among years in the timing of spring trap catches may have been related to water temperature (Fig. 1). The dates of first capture in 1989 (May 21) and 1991 (May 19) were similar, but the date of first capture in 1990 (April 26) was much earlier. In each of the three years, white perch did not appear in the traps until after the water temperature first reached 18°C, but that occurred earlier in 1990 than in 1989 or 1991 (Fig. 1). In 1992, only 17 white perch were collected prior to May 11. On that date, when water temperature first measured 17°C, 75 individuals were collected (Fig. 1). In 1993, an unusually cool, wet spring with high discharge, high catches were recorded at cooler temperatures than in previous years, but the highest daily catch (93) occurred on June 11 when the water temperature first reached 19°C. Analysis of variance revealed that weighted mean temperature of capture (Table 1) differed significantly among years ($F_{4,2236}$ = 300.6, P = 0.000), as did weighted mean date of capture ($F_{4,2236}$ = 126.8, P = 0.000).

In 1990, sex was determined for 171 of 189 white perch. The numbers of males (100) and females (71) were significantly different from what would be expected under the null hypothesis that the two sexes were equally abundant and equally susceptible to capture (normal approximation to the binomial test, P < 0.05). Although there was great overlap between the two sexes, the mean date of capture for males (May 6) was significantly different from that for females (May 9) (t = -3.58, P = 0.0006), indicating that males move upriver slightly prior to females.

Ages were estimated from scales of 10 fish collected in 1989 and 170 fish collected in 1990 (Table 2). In both years, several age classes were present, but age IV+ fish were most abundant. Based on the 1990 data, there was no difference between sexes in the relative numbers of individuals of different ages (chi-squared test of independence, with age II pooled with III and age V pooled with VI to keep all expected values greater than five, x^2= 0.769).

The size distributions of white perch collected in the traps differed among years (Fig. 2). In 1989, one fish with a TL of 115 mm was collected, and nine were in the TL range of 192–230 mm. In 1990, TL ranged from 162 mm to 242 mm, but most individuals fell within 180–210 mm (body mass in 1990 ranged from 53 g to 246 g). In 1991,

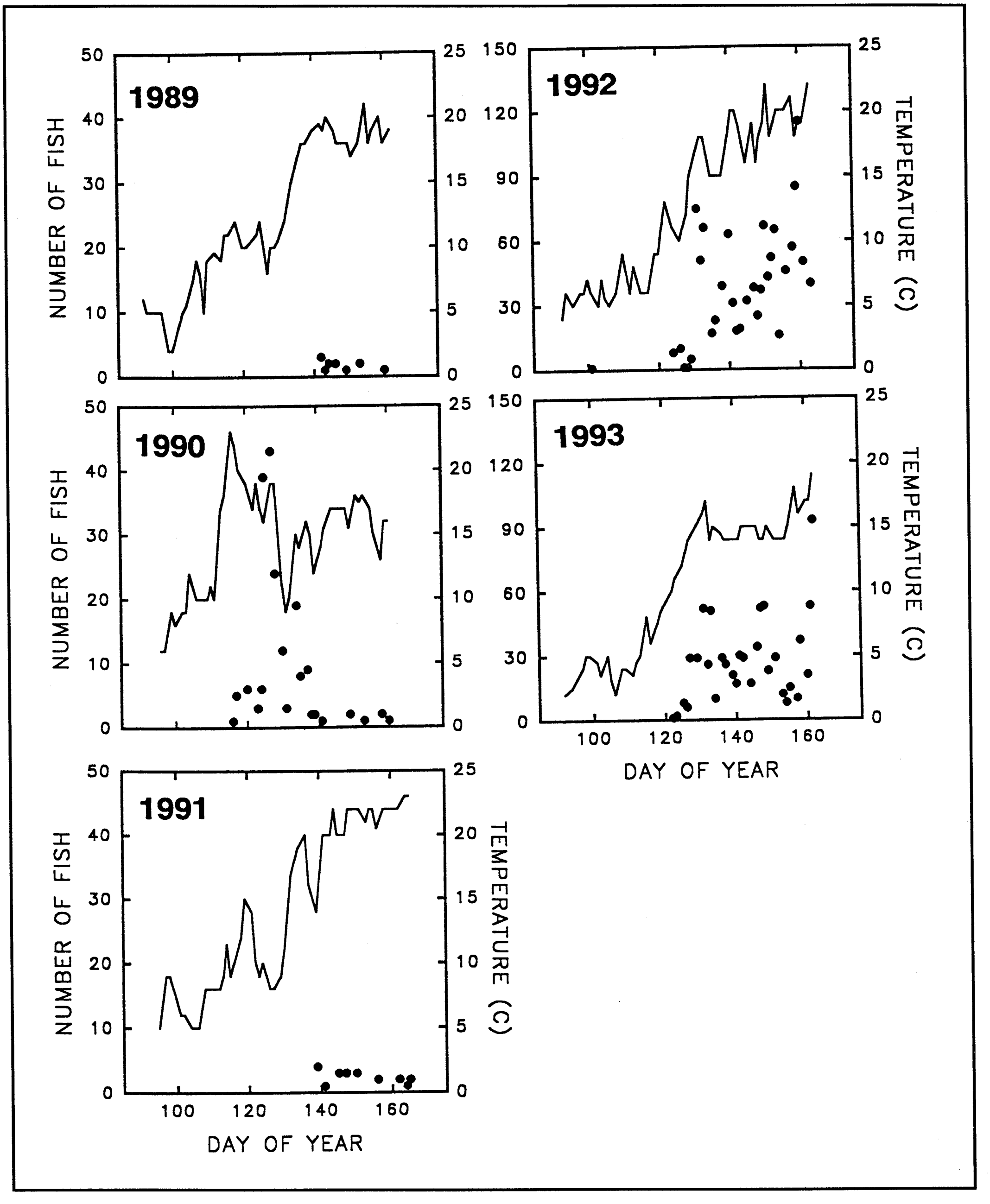

Fig. 1. Number of white perch collected in sea lamprey assessment traps and water temperature versus day of year during 1989–1993. Note that the left vertical scale for the years 1989–1991 is different from that for 1992–1993.

Table 2. Ages of ten of twelve white perch collected in 1989 and 170 of 189 white perch collected in 1990, followed by mean total length in millimeters and mean body mass in grams. Means are followed by standard errors (SE) in parentheses and associated sample sizes. 1990 data are partitioned by sex. Not all fish were measured for both length and body mass.

Age	*1989*	*1990*		
		Males	*Females*	*Unsexed*
		Total Sample Size		
I	1	0	0	0
II	0	1	0	0
III	1	29	21	3
IV	6	56	37	0
V	1	11	10	0
VI	1	0	1	1
		Total Length (mm), SE, Sample Size		
I	-	-	-	-
II	-	188 (0) 1	-	-
III	-	187 (1.6) 29	190 (2.3) 21	187 (1.45) 3
IV	-	193 (1.2) 56	200 (1.3) 37	-
V	-	212 (6.2) 11	204 (2.9) 10	-
VI	-	-	205 (0) 1	196 (0) 1
		Body Mass (g), SE, Sample Size		
I	-	-	-	-
II	-	-	-	-
III	-	102.0 (3.67) 19	97.8 (6.39) 13	86.7 (2.66) 3
IV	-	107.8 (1.84) 47	127.8 (4.00) 16	-
V	-	149.6 (13.40) 11	131.0 (10.10) 6	-
VI	-	-	129.0 (0) 1	105 (0) 1

twelve fish ranged in TL from 103 mm to 126 mm and nine fish ranged from 185 mm to 231 mm.

Based on ages estimated from scales of fish collected in 1989 and 1990, growth rate declined with age (Fig. 3).

Linear regressions of the natural logarithm of body mass (LNWT) on the natural logarithm of total length (LNTL) were calculated with 1990 data for both sexes pooled and for each sex individually. For all fish, LNWT = -10.7 + 2.92 LNTL (r^2 = 0.866, n = 116). For males, LNWT = -10.3 + 2.85 LNTL (r^2 = 0.869, n = 80), and for females, LNWT = -11.6 + 3.08 LNTL (r^2 = 0.891, n = 31). Analysis of covariance failed to reveal a significant difference between the regressions for the two sexes.

Although we occasionally electrofished above the De Pere dam throughout the course of this study, we collected no white perch above the dam until September 23, 1993, when two small individuals (TL: 64 and 72 mm) were captured along the St. Norbert College shoreline. These were probably young-of-the-year.

Discussion

If the catch of white perch in the lamprey assessment trap is a reliable index of their abundance, then the white perch population increased dramatically from 1988, when they were first discovered in the Green Bay/ Fox River system, until 1993, when they represented 24% of the total spring fish catch (Table 1). In at least one location in the Great Lakes, the Bay of Quinte of Lake Ontario, white perch rapidly became a dominant component of the fish assemblage within a few years of their invasion, only to undergo a dramatic decline attributed either to severe winter weather or to increased piscivore abundance (Hurley 1986). In Lake Erie, however, white perch first invaded in the 1950s but did not increase in abundance substantially until the 1970s (Schaeffer and Margraf 1986b). Johnson and Evans (1990) suggested that the Great Lakes distribution of white perch is limited by low tolerance of cold temperatures. They pointed out that the current distributional limit approximates the -5°C winter air isotherm. Since Green Bay lies slightly outside that isotherm, its white perch populations might be expected to fluctuate in response to year-to-year climatic variability.

We interpret at least part of our spring catch of white perch to represent the result of an upstream spawning migration, although our samples and reports by local anglers indicate that at least some white perch are present in the river outside of the spawning season. Sea lamprey assessment traps are positioned to capture fish whose movement upstream has been blocked by a dam or other barrier. At least some of the white perch we captured in this manner were in spawning condition (i.e., milt was freely expressed by some males), and they displayed the bluish cast reported on the lower jaws

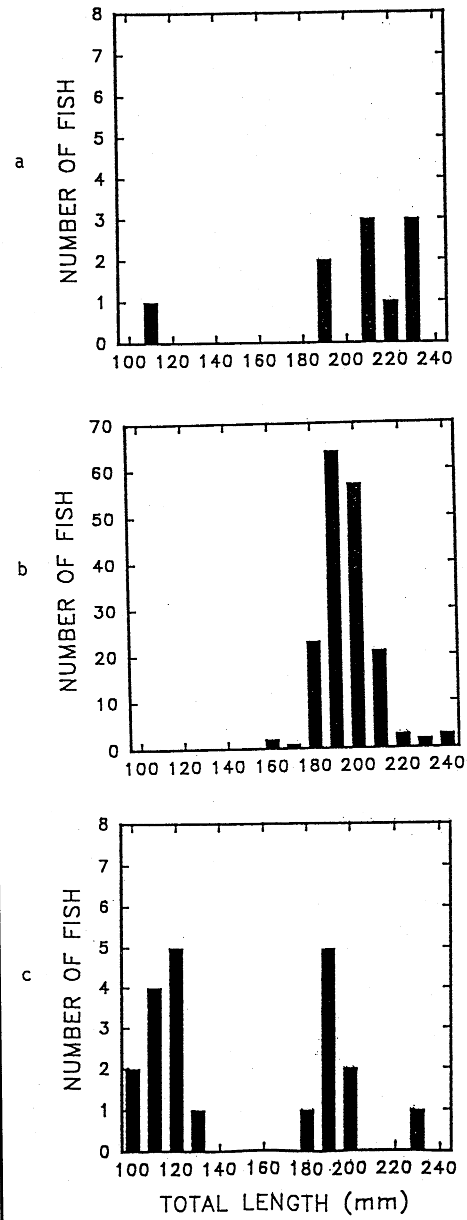

Fig. 2. Frequency histograms of total length of white perch collected in (a) 1989 (n=10), (b) 1990 (n=176), and (c) 1991 (n=21). Note that the vertical scale for the 1990 histogram is different from that for 1989 and 1991.

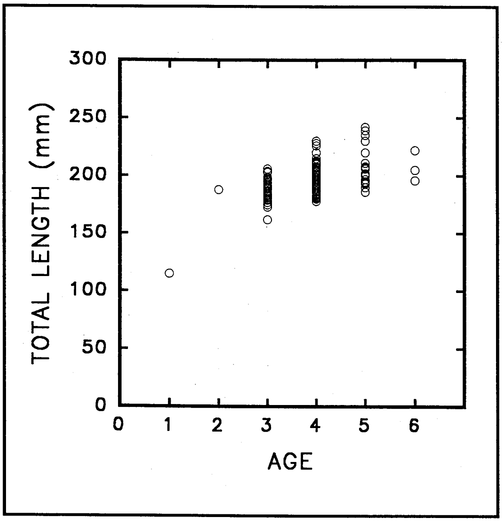

Fig. 3. Total length versus estimated age of white perch collected in 1989 and 1990

of spawning adults (Scott and Crossman 197; Smith 1985). Moreover, both Smith (1985) and Schaeffer and Margraf (1987) indicated that spawning peaked when water temperature reached 18°C, the approximate temperature at which white perch first appeared in abundance in our traps. Most of the fish we captured were above the size and age of maturity reported for white perch in Lake Erie (Schaeffer and Margraf 1986b). The modal group of smaller fish in 1991 (Fig. 2) may have been prereproductive, but in 1992 we noted fish as small as 112 mm from which milt was freely expressed.

Our interpretations of age and growth must be accepted with caution until the use of scales for aging white perch in this system has been validated. Nevertheless, our results indicated that white perch in the Green Bay system grow relatively quickly, especially early in their life, and that growth is comparable to that by white perch in Lake Erie (Schaeffer and Margraf 1986b). However, this species tends in freshwater habitats to become overpopulated, resulting in slower growth and an abundance of stunted individuals (Scott and Crossman 1973).

The presence of several age classes of white perch in the Fox River in 1989 and 1990 (Table 2) suggests either that white perch were present in the area and reproducing for several years prior to their discovery in 1988 or that their initial colonization involved large numbers of individuals, perhaps by multiple introductions (e.g., bilgewater release by freighters). In either case, the lamprey assessment trap did not capture white perch until a year after they were known to be present in the Fox River. This lapse between the occurrence and detection of an exotic species is especially relevant to the operation of the lamprey trap in the Fox River. The trap has been monitored each spring since 1979 because of concern that water quality improvements might be followed by the movement of spawning-phase sea lampreys up into the river. Indeed, a sea lamprey was collected in the trap for the first time in 1991 (Cochran 1994), but in light of our experience with white perch, it is quite possible that sea lampreys occurred in the river in prior years.

Although white perch were present in the lower Fox River as early as 1988, we did not collect them above the De Pere dam until 1993. During part of the spring spawning period, the De Pere lock channel is not yet open to boat traffic (it typically is opened at the end of May), and this may have delayed dispersal past the dam. We have, however, trapped white perch below the dam on dates after the locks were in operation. Spawning white perch from Lake Erie move at least 45 km up into tributary streams (Schaeffer and Margraf 1987), and it would seem inevitable that white perch would eventually traverse the 48 km between Green Bay and Lake Winnebago, where their presence could have substantial effects on important fisheries. Fortuitously, however, upstream movement by white perch toward Lake Winnebago has been blocked by the sealing of the Rapide Croche lock at the third dam upstream from Green Bay. This action was somewhat controversial when it was undertaken early in 1988 in anticipation of an invasion by sea lampreys. In retrospect, it may have been just in time to stop white perch.

Dams may eventually play an important role in limiting dispersal by white perch into other parts of Wisconsin. Now that they have invaded the Mississippi River in Illinois (Blodgett 1993), white perch can be expected to re-enter Wisconsin through the Mississippi River and its tributaries, some of which are impounded by impassable dams. For example, upstream dispersal in the Wisconsin River will be blocked by the Prairie du Sac dam, preventing access to a large area in north central Wisconsin.

At present, white perch in Wisconsin are apparently concentrated in the lower Fox River and southern Green Bay. They have not been collected in sea lamprey assessment traps operated in Green Bay tributaries other than the Fox River (i.e., the Menominee, Peshtigo, and Oconto rivers). Moreover, although they have been collected in Lake Michigan near Chicago (Savitz et al. 1989), they have not been taken in lamprey traps in the East Twin River, a tributary to Lake Michigan in Manitowoc County.

More information is needed to fully evaluate the ecological impact of white perch on the Green Bay/Fox River system, including their effects on the recently revitalized walleye (*Stizostedion vitreum*) and yellow perch (*Perca flavescens*) fisheries. In particular, the extent to which white perch feed on walleye eggs should be assessed, because they are known to feed on walleye eggs in the Lake Erie basin (Schaeffer and Margraf 1987). In addition, the extent to which walleye and other piscivores use white perch as forage should be investigated. Finally, efforts should be made to minimize the spread of this exotic species within Wisconsin's inland waters.

Acknowledgments

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Robert B. DuBois and Dennis M. Pratt

History of the fishes of the Bois Brule River System, Wisconsin, with emphasis on the salmonids and their management

Abstract *The Bois Brule River in Douglas County is one of Wisconsin's largest, best known, and most intensively studied trout streams. A diverse fish fauna of at least 63 species (11 of which are exotic, plus one cultured hybrid) has been collected from the watershed. However, only 21 are coldwater, riverine species with viable populations; the remainder are either lentic, warmwater forms found in lakes Minnesuing and Nebagamon, are Lake Superior species that only occasionally enter the lower river, or are locally rare. The fish fauna has been profoundly altered by species introduced both intentionally and accidentally, and by control efforts directed at the exotic sea lamprey* (Petromyzon marinus), *which have caused severe density and distribution reductions in two species of native lampreys. Once sustaining a population of native brook trout* (Salvelinus fontinalis) *as the only angling target, the river now provides angling opportunities for four species of exotic salmonids as well. Declines in several of the salmonid populations, especially during the last two decades, may be attributable to over-exploitation; consequently, fishery regulations have become increasingly restrictive. Top priority, however, will continue to be maintenance of excellent habitat and water quality. With fine riparian stewardship practiced by private landowners, coupled with the state stewardship land acquisition program within state forest boundaries, this focus appears to be sustainable. Other habitat management efforts have included in-stream habitat enhancement techniques, beaver* (Castor canadensis) *control and dam removal, dredging projects, and bank stabilization efforts in red clay areas prone to slippage.*

The Bois Brule River (hereafter referred to as the Brule River) in Douglas County is perhaps the most famous trout stream in Wisconsin (O'Donnell 1944). Its fame is related both to its rich history as an important water route, linking Lake Superior and the upper Mississippi River drainage, and its historic reputation for excellent trout fishing (O'Donnell 1944; Marshall 1954). Additionally, the river has long been renowned for its beauty and an intangible mystique that repeatedly draws anglers and canoeists alike back to its waters. Today the Brule River provides habitat for a diverse array of coldwater organisms in addition to the salmonids. As one of the larger spring-fed streams in the Midwest, it is a regionally unique resource deserving the highest level of protection.

The original renowned trout fishery of the Brule River bore little resemblance to the current fishery for five salmonid species. During the middle and late 1800s the river was widely acclaimed for its native brook trout (*Salvelinus fontinalis*) fishing; this fishery was comprised of both stream-resident and anadromous, or coaster[1], components. Unfortunately, this fishery had begun to decline sharply by the turn of the century (Jerrard 1956), probably from a combination of over-exploitation, habitat loss, and logging dam effects (O'Donnell 1944). However, subsequent introductions of steelhead (anadromous rainbow trout, *Oncorhynchus mykiss*), brown trout (*Salmo trutta*), and various brook trout strains, in combination with increasingly restrictive angling regulations and termination of extensive logging, helped bolster the fishery back into prominence. High quality trophy fisheries for anadromous brown trout, steelhead, and more recently, coho salmon (*Oncorhynchus kisutch*) and chinook salmon (*Oncorhynchus tshawytscha*) have since developed and are augmented by challenging upper river and tributary fisheries for stream-resident brook trout and brown trout.

Throughout the recorded history of this river, anglers have often voiced complaints related to perceived dips in the quality of fishing. In 1983 an advisory task force (the Brule River Committee) was formed in response to perceived declines in populations of both steelhead and brown trout. The committee was formed of Wisconsin Department of Natural Resources (WDNR) personnel and concerned citizens representing area sports clubs. Objectives for the committee were to identify and prioritize the most pressing fishery problems and formulate suggestions for remedial actions. Most of the problems identified pointed to a common need: to promptly initiate a long-term, comprehensive research project to provide quantitative data about the salmonid populations. Although the river had been the focus of much investigation since the 1940s (see section on ecological investigations), the descriptive information obtained was of limited value for guiding management actions. Late in 1983 the WDNR initiated a broadly based research initiative to provide the information on salmonid population dynamics needed to optimize management of the fishery.

This report grew out of the research effort initiated in 1983 and presents an historical sketch of the fish populations of the Brule River system along with the factors that have affected them over the last two centuries. Our emphasis regarding these objectives is focused primarily on the salmonids and their management, and secondarily on the exotic sea lamprey (*Petromyzon marinus*), because these species have received the most management and research attention. However, because these species are just part of a diverse fish community, we also summarize the information available, both historical and recent, for all fish species within the river system.

Methods

This report represents a compilation of information taken from a variety of sources including data collected by the authors during various phases of a multifaceted salmonid research project on the Brule River during 1983–93, file data from the WDNR Brule Area and Superior offices, and numerous published sources. Works by O'Donnell (1944), Holbrook (1949), Marshall (1954), and Jerrard (1956) were instrumental in providing information about human development within the Brule River Valley and the historic trout fishery. Physical and chemical information for the mainstem[2] and tributaries were summarized from several sources. Fish distribution information was obtained either during WDNR fishery surveys over the last decade or from the sources acknowledged in Table 1. Both WDNR file data and published accounts of species distributions were used except in a few cases where they were clearly inconsistent with established information on statewide distributions (Becker 1983; Fago 1992). Collections from 44 sampling stations located throughout lotic areas of the river system during 1987–91 (DuBois et al. in press) targeted juvenile and stream-resident salmonids and were made with standard WDNR stream electrofishing units using 220 volt direct-current generators; electrofishing surveys prior to about 1980 used less efficient (on salmonids) alternating-current generators. Spawning runs of anadromous salmonids were examined with a viewing window and sea lamprey trap at the sea lamprey barrier/fishway (hereafter referred to as the barrier/fishway – Fig. 1). Smolts were studied with an inclined-screen trap (DuBois et al. 1991) below[2] the barrier/fishway.

Sport fishery statistics were summarized from WDNR creel surveys conducted in 1973, 1978–79, 1984, and 1986 on the mainstem from Stone's Bridge to the mouth, in 1990 on the lower river[2] only, and in 1992 on the upper river[2] only. Random, stratified, timed-interval designs—also known as bus route designs (Jones and Robson 1991)—were used to obtain completed trip interviews at major access points in 1986, 1990, and 1992; earlier access-point surveys were not stratified according to anticipated angling pressure. Information requested from each angler included the length of time fished, fishing methods used, data about the catch, and perceptions of the fishing experience. Creeled salmonids were measured to the nearest 0.1 inch and scale-sampled as needed for age analysis.

The Physical Setting

The 47-mile-long Brule River drains a watershed of about 130 square miles and flows north into Lake Superior (Fig. 1). The average discharge near the WDNR Brule Area Headquarters on the river's midsection is 169 ft^3/sec with extremes ranging from 67 to 1,520 ft^3/sec (Niemuth 1967); this flow regime is relatively stable for a large stream in Wisconsin (Bean and Thomson 1944; Sather and Johannes 1973). The upper sections of river originate in, and flow through, a large conifer bog surrounded by a sandy outwash plain known as the "pine barrens." This area acts as a sponge by absorbing a high percentage of the rainfall entering the region, and then delivering it to the stream through numerous springs at a uniform rate (Bean and Thomson 1944). The high input of spring flow is the defining feature of the river system. This uniform source of abundant ground water creates stable flows and a moderated thermal regime, which is cooler

Table 1. Relative abundance and distribution of fish species of the Brule River system

Common Name	*Scientific Name*	*Origin*	*Relative Abundance1*	*Information sources2*
PETROMYZONTIDAE				
Silver Lamprey	*Ichthyomyzon unicuspis*	Native	R	AU; SG; LB; MC; US
Northern Brook Lamprey	*Ichthyomyzon fossor*	Native	R	CH; OD; US
Sea Lamprey	*Petromyzon marinus*	Exotic	C	AU; LB; MC; MO; WI
LEPISOSTEIDAE				
Longnose Gar	*Lepisosteus osseus*	Native	R	MO; WI
ANGUILLIDAE				
American Eel	*Anguilla rostrata*	Exotic	R	AU; FB
CYPRINIDAE				
Common Carp	*Cyprinus carpio*	Exotic	R	LB
Golden Shiner	*Notemigonus crysoleucas*	Native	O	AU; FB; GR; LB; MC; MO; WI
Creek Chub	*Semotilus atromaculatus*	Native	C	AU; FB; GR; LB; MC; MO; OD; WI
Pearl Dace	*Margariscus margarita*	Native	U	AU; FB; MO; WI
Finescale Dace	*Phoxinus neogaeus*	Native	R	MO; WI
Northern Redbelly Dace	*Phoxinus eos*	Native	O	AU; FB; MO; OD; WI
Lake Chub	*Couesius plumbeus*	Native	C	MC, MO, OD; WI
Blacknose Dace	*Rhinichthys atratulus*	Native	C	AU; FB; GR; LB; MO; OD; WI
Longnose Dace	*Rhinichthys cataractae*	Native	A	AU; FB; GR; LB; MC; MO; OD; WI
Hornyhead Chub	*Nocomis biguttatus*	Native	C	MC; LB; MO; WI
Common Shiner	*Luxilus cornutus*	Native	C	AU; FB; LB; MC; MO; OD; WI
Emerald Shiner	*Notropis atherinoides*	Native	R	FB; LB; MO; OD; WI
Spottail Shiner	*Notropis hudsonius*	Native	O	AU; GR; LB; MC; MO; WI
Mimic Shiner	*Notropis volucellus*	Native	U	AU
Blacknose Shiner	*Notropis heterolepis*	Native	R	FB; MO; WI
Brassy Minnow	*Hybognathus hankinsoni*	Native	U	AU; FB; MO; WI
Bluntnose Minnow	*Pimephales notatus*	Native	O	FB; GR; MO; WI
Fathead Minnow	*Pimephales promelas*	Native	U	AU; FB; GR; MO; WI
CATOSTOMIDAE[3]				
Silver Redhorse	*Moxostoma anisurum*	Native	O	AU; MO; OD; WI
Shorthead Redhorse	*Moxostoma macrolepidotum*	Native	O	AU; LB; MC; MO; OD; WI
White Sucker	*Catostomus commersoni*	Native	A	AU; FB; GR; LB; MC; MO; OD; WI
Longnose Sucker	*Catostomus catostomus*	Native	C	AU; LB; MC; MO; OD; WI
ICTALURIDAE				
Black Bullhead	*Ameiurus melas*	Native	U	AU; FB; LB; MC; MO; OD; WI
Brown Bullhead	*Ameiurus nebulosus*	Native	R	MO; WI
Yellow Bullhead	*Ameiurus natalis*	Native	R	FB; MO; WI
Tadpole Madtom	*Noturus gyrinus*	Native	R	OD
Stonecat	*Noturus flavus*	Native	O	AU; MC; MO; WI
ESOCIDAE[4]				
Northern Pike	*Esox lucius*	Native	C	AU; FB; GR; LB; MC; MO; OD; WI
UMBRIDAE				
Central Mudminnow	*Umbra limi*	Native	C	AU; FB; GR; MO; OD; WI
OSMERIDAE				
Rainbow Smelt	*Osmerus mordax*	Exotic	O	AU; MC; MO; OD; WI
SALMONIDAE				
Atlantic Salmon	*Salmon salar*	Exotic	R	AU; LB
Brown Trout	*Salmo trutta*	Exotic	A	AU;FB;GR;LB;MC;MO;OD;SC;WI
Chinook Salmon	*Oncorhynchus tshawytscha*	Exotic	C	AU; LB; SC; WI
Coho Salmon	*Oncorhynchus kisutch*	Exotic	A	AU; LB; SC
Steelhead	*Oncorhynchus mykiss*	Exotic	A	AU;FB;GR;LB;MC;MO;OD;SC;WI

(Taxonomic names and order of families follows Robins et al. [1991].)

Main Areas of Distribution

lowest mile of the lower river; greatly reduced by lampricide treatments that began in 1959
lower two thirds of the mainstem and several tributaries prior to lampricide treatments that began in 1959; now Minnesuing and upper Nebagamon creeks
much of the mainstem and larger tributaries until restricted by the lamprey barrier in 1986; now below the barrier

one specimen reported from the lowest mile of the lower river

specimens reported from the estuary and Lake Nebagamon

lower river up to the lamprey barrier
the lowest few miles of the mainstem and Lake Minnesuing
scattered throughout the lower river; most common in slow water in the larger tributaries
lower river, Casey, Blueberry, and Wilson creeks, West Fork, and Lake Minnesuing
the lowest several miles of the lower river
lower river and most of the tributaries
lowest mile of the lower river
entire mainstem and Trask, Casey, and Blueberry creeks
riffle areas throughout the mainstem and in the larger tributaries
lowest mile of the lower river
lower river up to the lamprey barrier and Trask Creek
lower river up to the lamprey barrier and Lake Minnesuing
lower river up to the lamprey barrier
estuary
lowest mile of the lower river and Lake Minnesuing
lower river and larger tributaries
lowest mile of the lower river, Blueberry Creek, and Lake Minnesuing
lowest several miles of the lower river, Casey and Wilson creeks, Rocky Run, and the East Fork

lowest several miles of the lower river
lowest several miles of the lower river
entire mainstem and the larger tributaries
most common in the lowest several miles of the lower river but occasionally as far upstream as Winneboujou

slow, deep sections of the mainstem, Nebagamon Creek, and lakes Nebagamon and Minnesuing
lowest mile of the lower river
lowest mile of the lower river and Lake Minnesuing
one specimen reported from the lower river at McNeil's Bridge
lower river below the lamprey barrier

lakes Nebagamon and Minnesuing, uncommonly reported from scattered lotic sections

midsection and lower river except for extreme lowermost section and most of the tributaries

lowest mile of the lower river

occurrence/extent of reproduction in the Brule River system is unknown; probably strays from others waters
the larger tributaries and most of the mainstem, except for the extreme uppermost and lowermost sections
midsection of the mainstem and Nebagamon and Blueberry creeks
upper river mostly above Stone's Bridge, Rocky Run, Blueberry Creek, Jerseth Creek, East Fork
entire mainstem (but less common in the extreme uppermost and lowermost sections) and the larger tributaries

Table 1 continued

Common Name	*Scientific Name*	*Origin*	*Relative Abundance1*	*Information sources2*
SALMONIDAE (CONT.)				
Pink Salmon	*Oncorhynchus gorbuscha*	Exotic	R	SC
Brook Trout	*Salvelinus fontinalis*	Native	A	AU; FB; GR; LB; MC; MO; OD; WI
Lake Trout	*Salvelinus namaycush*	Native	R	LB
Splake	Lake trout X Brook trout	Exotic Hybrid	U	LB
Lake Herring	*Coregonus artedi*	Native	R	MO; WI
Round Whitefish	*Prosopium cylindraceum*	Native	U	AU; LB; MO
PERCOPSIDAE				
Trout-perch	*Percopsis omiscomaycus*	Native	U	AU; LB; MC; MO; OD; WI
GADIDAE				
Burbot	*Lota lota*	Native	O	AU; LB; MC; MO; WI
GASTEROSTEIDAE				
Brook Stickleback	*Culaea inconstans*	Native	C	AU; FB; GR; MO; OD; WI
Ninespine Stickleback	*Pungitius pungitius*	Native	R	MO; WI
COTTIDAE[5]				
Mottled Sculpin	*Cottus bairdi*	Native	A	AU; FB; GR; MC; MO; OD; WI
Slimy Sculpin	*Cottus cognatus*	Native	A	AU; GR; MO; WI
CENTRARCHIDAE				
Smallmouth Bass	*Micropterus dolomieu*	Native	C	AU; FB; GR; LB; MC; MO; WI
Largemouth Bass	*Micropterus salmoides*	Native	C	AU; FB; GR; MO; WI
Pumpkinseed	*Lepomis gibbosus*	Native	A	AU; FB; GR; MC; MO; WI
Bluegill	*Lepomis macrochirus*	Native	A	AU; FB; GR; LB; MO; OD; WI
Rock Bass	*Ambloplites rupestris*	Native	C	AU; FB; GR; LB; MC; MO; OD; WI
Black Crappie	*Pomoxis nigromaculatus*	Native	A	AU; FB; MO; WI
PERCIDAE				
Walleye	*Stizostedion vitreum*	Native	C	AU; FB; LB; MC; MO; OD; WI
Yellow Perch	*Perca flavescens*	Native	A	AU; FB; GR; LB; MC; MO; OD; WI
Logperch	*Percina caprodes*	Native	O	AU; LB; MC; MO; OD; WI
Johnny Darter	*Etheostoma nigrum*	Native	C	AU; FB; GR; MC; MO; OD; WI
Iowa Darter	*Etheostoma exile*	Native	R	AU; FB; GR; MO; WI
Ruffe	*Gymnocephalus cernuus*	Exotic	C	LB; PR

[1]A = abundant – species often collected in large numbers.
C = common – species often collected in moderate numbers.
O = occasional – species occasionally collected in moderate or small numbers.
U = uncommon – species infrequently collected in small numbers.
R = rare – species collected at rare intervals in very small numbers.

[2]AU – authors collections; CH – Churchill 1945; FB – WDNR Fisheries Management file data (Brule Area Office); GR – Greene 1935; LB – WDNR lamprey barrier trap 1986 – 1993; MO – Moore and Braem 1965; MC – McLain et al. 1965; PR – Pratt et al. 1992; OD – O'Donnell and Churchill 1954; SC – Scholl et al. 1984; SG – Schuldt and Goold 1980; US – USFWS data files (J. Heinrich, pers. comm.); WI – Wisconsin Fish Distribution Study (cited by Fago 1992).

[3]O'Donnell and Churchill (1954) reported the golden redhorse (*Moxostoma erythrurum*) to be common in the estuary; based on current distribution information this is likely to have been a misidentification—their specimens probably were shorthead redhorse or silver redhorse.

Main Areas of Distribution
not consistently reproducing in the Brule River system since 1979; rarely strays from other waters
upper river and most of the tributaries
transient from Lake Superior into the lower river up to the lamprey barrier
transient from stocking programs elsewhere in Lake Superior
lowest mile of the lower river
lowest several miles of the lower river
lower river, becoming increasingly common towards the mouth
lower river below the lamprey barrier
scattered throughout the mainstem and most of the tributaries in weedy, slow-water areas
lowest mile of the lower river
entire mainstem but least common in cold, headwater areas; Trask, Blueberry, and Nebagamon creeks
colder tributaries and headwater areas; present but less common throughout most of the mainstem
lakes Nebagamon and Minnesuing; rarely reported from scattered mainstem and tributary areas
lakes Nebagamon and Minnesuing; rarely reported from scattered mainstem areas
lakes Nebagamon and Minnesuing; rarely reported from scattered mainstem and tributary areas
lakes Nebagamon and Minnesuing, and Nebagamon Creek; rarely reported from scattered mainstem areas
lakes Nebagamon and Minnesuing, and Nebagamon Creek; rarely reported from scattered mainstem areas
lakes Nebagamon and Minnesuing; rarely reported from scattered mainstem and tributary areas
lakes Nebagamon and Minnesuing; uncommonly reported from the lower river below the lamprey barrier
lakes Nebagamon and Minnesuing, and Nebagamon Creek; rarely reported from the lower river below the lamprey barrier
lower river up tp the lamprey barrier
entire mainstem, Trask and Blueberry creeks, East Fork, West Fork, and Lake Minnesuing
lowest mile of the lower river, Blueberry Creek, and Lake Minnesuing
lower river below the lamprey barrier; most common in the estuary

[4]In the early 1900s, some specimens of grass pickerel (*Esox americanus*) were reported from Lake Nebagamon (Fago 1992). These reports were probably erroneous because Lake Nebagamon is well outside of the known range of this species, and in early years northern pike were sometimes referred to as grass pickerel and walleye were often called pickerel. It is possible that true grass pickerel were introduced into Lake Nebagamon, but that a viable population failed to become established.

[5]There appear to be overlapping distributions of mottled and slimy sculpins throughout the mainstem and in the tributaries, with mottled sculpins predominating in the mainstem and the warmer tributaries and slimy sculpins predominating in the colder tributaries. Although the limited data collected are consistent with this pattern, the conclusion is tentative because separation of these species in the field is difficult and specimens from relatively few sites were examined in the laboratory.

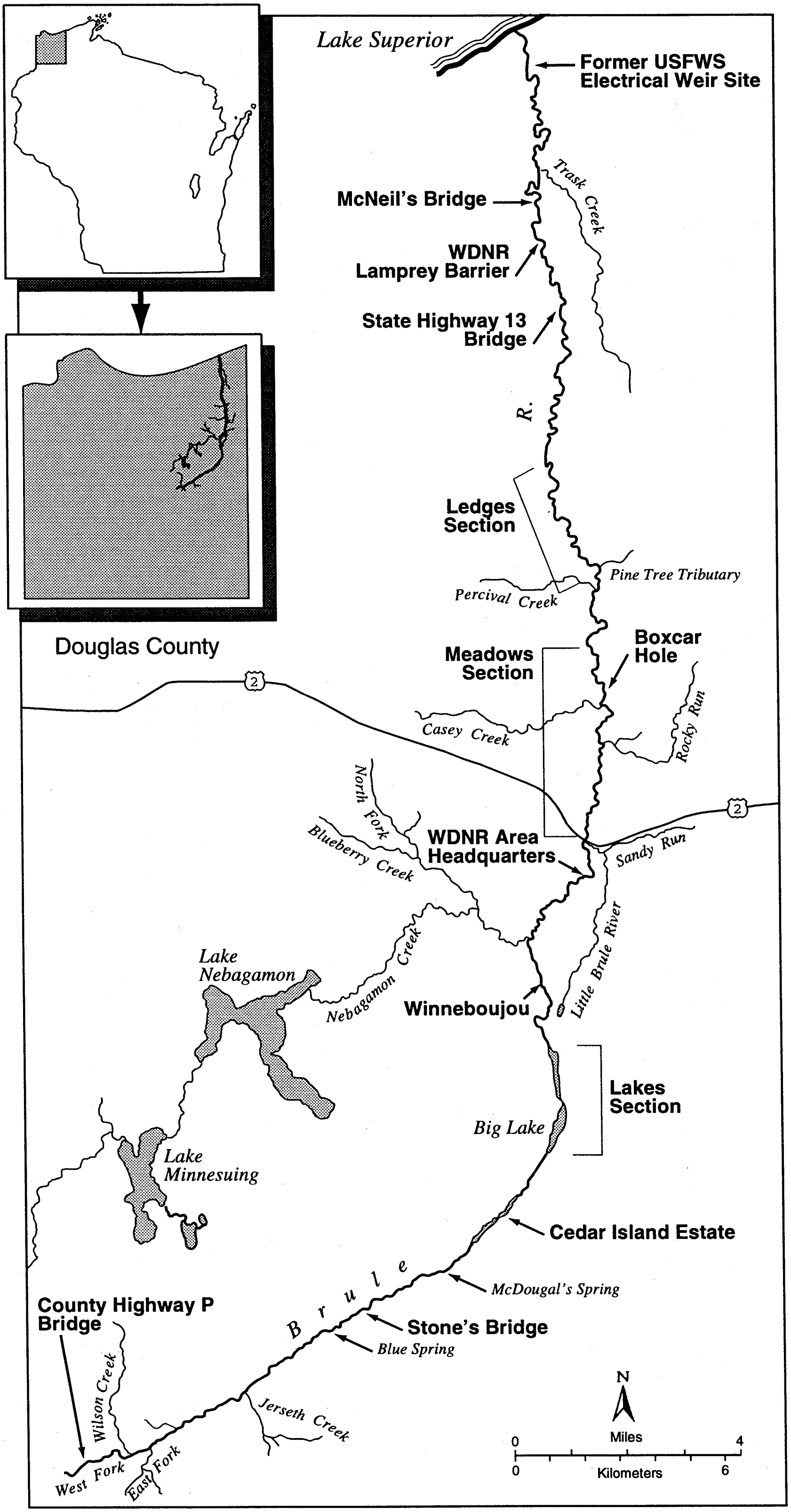

Fig. 1. Map of the Bois Brule River study area including major tributaries

in summer and warmer in winter than most streams its size (both characteristics are most evident in the upper reaches). The lower river flows through a region of red clay that contributes high runoff and associated turbidity and siltation to this section during pluvial periods. A longitudinal gradient of water temperature consists of less thermal moderation as the river proceeds to its mouth. In winter, the lower river is heavily ice-covered, and during warm summers, water temperature in the lowest section is marginal for salmonids. Patterns of spring flow and water temperature probably existed historically much as they do today. The physical and chemical characteristics of the river system are summarized in Table 2; more detailed descriptions of the geology and topography of the watershed (Bean and Thomson 1944; Dickas and Tychsen 1969), the forest cover types within the Brule Valley (Fassett 1944; Thomson 1945), and the chemical aspects of the river system (Bahnick et al. 1969) are also available.

History of Human Activity Within the Brule River Watershed as Related to the Fish Community

The Brule River is renowned for its relatively undisturbed natural setting, and indeed it has weathered human encroachment with less disturbance than most large streams in Wisconsin. Nonetheless, changes to its physical setting have occurred during the last century that may have affected the fish community. Early accounts of explorers' journeys up the Brule River mention the presence of one hundred or more beaver (*Castor canadensis*) dams that had to be broken through (Marshall 1954). Locations of these dams are not given, but they were probably most abundant in the upper river above the Cedar Island estate area (Fig. 1). Beaver were heavily trapped in 1803–04, and the dams were subsequently removed by the military to facilitate use of the river as a water route between the Great Lakes and the Mississippi River prior to the development of a military road network (Marshall 1954). These dams may have hindered brook trout movement to spawning areas (Marshall 1954), and accounts reporting excellent trout fishing are commonly found only after removal of most dams in about 1830 (O'Donnell 1944; Marshall 1954; Jerrard 1956).

Aboriginal fish harvest from the Brule River for centuries had undoubtedly been modest; recent research indicates that the Chippewa who settled along the southern littoral of Lake Superior did not rely on fish for their primary subsistence (Kaups 1984). Access to the river for European settlers prior to about 1850 was by water along Lake Superior, mostly from the city of Superior (Marshall 1954). Travel upriver was time-consuming and arduous, and the bark canoes used required skillful handling and frequent repair from damage caused by striking rocks. Hence, the brunt of early fishing probably took place near the mouth of the river. The first record of fish caught from the Brule River comes from the journal of Michel Curot who set two gill nets near the mouth of the river in 1804 and caught eight unidentified fish (Wisconsin Historical Society 1911).

Increased angling pressure on other sections of river began when overland access improved following the cutting of a crude wagon trail from St. Paul to Bayfield in 1850 (Marshall 1954). This trail passed through the town of Gordon (then called Amik), and an early road cut from Gordon to the Brule River about two miles south of Cedar Island soon followed (Marshall 1954). As early as 1855, canoes and Mackinaw boats complete with crews for fishing were advertised for

Table 2. Mean physical and chemical characteristics of the lower Brule River[1], the upper Brule River[2], and 14 tributaries for which reliable fish distribution information exists (compiled from data collected by the authors, from Fisheries Management files [Brule Area and Superior Offices], or from Sather and Johannes 1973; n/a means no data available).

Mainstem Section Or Tributary	*Mean Width (ft)*	*Mean Depth (inches)*	*Estimated Normal Discharge (ft3/s)*	*Mean Gradient (ft/mile)*	*pH*	*MPA (ppm)*	*Specific Conductance @ 77°F (umhos)*	*Approximate Maximum Summer Water Temperature (°F)*
Lower River	66	30	221	13	7.7	66	119	high 70's
Upper River[3]	54	30	97	6	7.5	45	106	high 60's
Trask Creek	7	6	2	55	7.6	123	237	at least mid 70's
Casey Creek	10	7	1	40	7.0	49	106	at least mid 70's
Percival Creek	4	2	<0.5	111	7.3	100	213	n/a
Pine Tree tributary	3	4	<0.5	264	n/a	n/a	n/a	n/a
Rocky Run	10	7	2	90	7.5	105	142	low 60's
Sandy Run	7	6	7	47	7.4	99	161	low 60's
Little Brule River	17	10	12	20	7.3	66	91	mid 60's
Nebagamon Creek	21	10	20	20	7.1	41	91	high 70's
Minnesuing Creek	20	10	3	2	7.3	45	98	at least high 70's
Blueberry Creek	11	10	5	29	6.4	26	70	low 70's
Jerseth Creek	5	4	1	71	7.2	43	84	high 50's
Wilson Creek	4	5	2	50	7.0	36	80	mid 60's
West Fork	15	6	2	5	7.3	66	134	low 70's
East Fork	15	14	4	23	7.3	42	83	high 50's

[1]Lower river refers to the stretch of river from U. S. Highway 2 north to Lake Superior

[2]Upper river refers to the stretch of river from U. S. Highway 2 south to the confluence of the East and West forks

[3]excluding Big Lake

hire in the Superior newspaper (*Superior Chronicle*, August 28, 1855). A fishing excursion on the Brulė River in 1862 was reported to have caught "a lot of trout weighing from four to five pounds each" (*Superior Chronicle*, August 23, 1862).

The period from 1870 through 1890 is noteworthy in the history of the Brule River because means of transportation for reaching the river improved dramatically, the countryside around the river was rapidly "filling up with immigrants" (Marshall 1954), and recreational use of the river steadily increased from that time on (Holbrook 1949; Marshall 1954). In 1870, the Bayfield trail was cut from Superior to Bayfield, and it quickly became an important artery (Marshall 1954; Jerrard 1956). Near the Brule River the Bayfield trail followed the Copper Range and crossed the river about two miles south of the present County Highway FF bridge. At first, this trail was usable by wagon only in winter until it was improved in 1876. During the early 1870s, Alexander McDougall caught bushels of trout through the ice from the Cedar Island spring ponds and shipped them by dogsled to the Bayfield trail, then by horse team to markets in Duluth (Marshall 1954). Several articles in the *Superior Times* during the mid-1870s indicated that angling parties were making fine sport catches from the river. During the 1880s another wagon trail was cut from the town of Solon Springs (then called White Birch) to the Blue Spring area of the upper river just south of Stone's Bridge. Access to the river was eased further by the development of a railway system. The Northern Pacific rail line from Duluth to Ashland was laid in 1883; this train crossed the river at the newly established town of Brule (Marshall 1954). In 1892, the laying of the Duluth and South Shore Railroad crossed the river at Station Rapids just south of the present County Highway B bridge (Marshall 1954). By 1884, Joe Lucius was operating a guiding service for anglers on the river, and by 1900, the river had been "well discovered by anglers" (Marshall 1954). Roads in the Brule area were first passable by automobile in 1914.

Much of the virgin timber within the Brule River valley was clear-cut beginning in the early 1890s; this activity ushered in a new era of human perturbation and development in the region (Jerrard 1956). Two logging dams (also called splash dams), one near the mouth of the river and the other about two miles north of the town of Brule (near the present Boxcar Hole), were built to facilitate movement of logs downriver (Marshall 1954; Jerrard 1956). These dams, although thought to be short-term, appear to have blocked the migration route of coaster brook trout at critical times and contributed to decline of the fishery (O'Donnell 1944). Also significant was damage caused to the streambed and shoreline areas when the dams were breached and large numbers of logs were run swiftly downstream (Marshall 1954). The extent of siltation, erosion, and subsequent flooding caused by timber cutting in riparian areas is uncertain but likely was substantial. Clearly, the logging dams and lumbering operations negatively affected the fishing, and fishing improved when these activities were terminated (O'Donnell 1944; Jerrard 1956). The late 1800s and early 1900s also saw increasing human activities regarding agriculture, road construction, and delivery of utilities within the watershed; the extent to which these activities may have harmed the fish populations is unknown.

The written record of human dwellings in the Brule River Valley begins with a Chippewa village at the mouth of the river during the late-1850s that exported large quantities of Lake Superior fish by sailing sloop

(Marshall 1954). At about the same time, several commercial fishers of European descent also maintained their fishing stations there, and exported large quantities of whitefish (*Coregonus clupeaformis*), siscowet (a "fat" morph of lake trout, *Salvelinus namaycush*), and lake trout (*Superior Chronicle*, May 1, 1859; also *Superior Times*, July 15, 1875). In 1880, Samuel Budgett established the town of Clevedon at the same location, but this community persisted for only about five years. Land on the present Cedar Island Estate was purchased in 1877 by two Minnesota men for the purpose of using the series of spring ponds on the property to commercially raise brook trout (*Superior Times*, January 27, 1877). In the late 1870s Frank Bowman built a cabin on this property (Marshall 1954). During the early 1880s, Henry Clay Pierce added to the now extensive Cedar Island Estate, and the first of the Winneboujou Club cabins were built. These were the first of the long-term dwellings that sprang up along the banks of the Brule River during the 1880s (Marshall 1954; The Winneboujou Club 1990). By the early 1900s, most of the permanent dwellings that now exist along the upper river had been completed. On the entire length of river, about four dozen permanent dwellings can now be found; this number is slowly shrinking as properties become available for public ownership through the state's land acquisition program.

In 1905, Pierce created a large fish hatchery at Cedar Island by blocking off the extensive system of interconnected spring ponds from the river; this action greatly reduced the amount of spawning area for the upper river brook trout population. These spring ponds had gravel bottoms with areas of upwelling ground water that provided excellent spawning habitat. Early accounts (summarized by O'Donnell 1944) affirm that these spring ponds were the primary spawning grounds of the original brook trout population. A major decline in the brook trout fishing apparently started about 1910, about five years after this spawning area was separated from the river proper (Jerrard 1956). Early reports by WDNR fishery workers (O'Donnell 1944; O'Donnell and Churchill 1954) recognized the tremendous spawning potential represented by the Cedar Island spring ponds and recommended state acquisition of the ponds to make them accessible once again as natural spawning grounds.

The State of Wisconsin built a fish hatchery on the Little Brule River, at about its midpoint (Fig. 1), in 1928. Still operating, this hatchery has always been used to meet statewide demands for domestic salmonids. It uses the entire flow of the Little Brule River for its water supply and creates a complete barrier to upstream fish movement. Run-of-the-river fish hatcheries like the ones on the Little Brule River and at Cedar Island, in addition to the positive effect of producing fish, have the potential to affect ecosystem health in negative ways as well. They can cause localized habitat destruction by their placement, downstream water pollution by their operation, and present a risk for disease outbreaks that can spread to adjacent wild populations. Although they have reduced critical habitats, there is no evidence to suggest that either hatchery within the Brule River system has negatively affected ecosystem health through disease outbreaks or substantial pollution.

The Brule River ecosystem is subject to considerable recreational activity apart from fishing, the byproducts of which could conceivably impact the fish community. Recreational canoe and kayak use is seasonally heavy, averaging about 13,000 people annually over the last ten years on the upper river alone, and use on the lower river is probably similar in magnitude (C. Zosel, WDNR, pers. comm.). The relatively pristine setting of the upper river, having two stretches exceeding eight miles in length without road crossings, provides a rare canoeing experience. Litter resulting inadvertently from spills is substantial given the volume of boat traffic. Tubing was a popular activity on the Brule River before it was banned in 1981 because of conflicts between tubers and other river users, and a myriad of other concerns. Issues of crowding and potential conflicts between anglers and recreational canoers have frequently surfaced and may ultimately need to be addressed by managers through some sort of usage allotment system as increases in both activities continue. Campgrounds on the middle and lower sections of river also draw numbers of recreationists into the watershed.

Ecological Investigations on the Brule River Watershed

While the Brule River has received fame as a quality trout stream, its history has been interspersed with perceived declines in fishing quality (Schneberger and Hasler 1944). Consequently, the river has been the focus of many studies to preserve and restore the fishery. These efforts have compiled a wealth of information about physical, chemical, and biological aspects of the river.

In the early 1940s, the Brule River and its watershed were subjected to one of the most exhaustive interdisciplinary studies ever done on a Wisconsin stream. The intent was to evaluate the physical, biological, and chemical characteristics of the watershed so that an efficient and well-balanced management plan could be developed by the WDNR (then the Wisconsin Conservation Department, WCC). Eleven technical papers were subsequently published in the *Transactions of the Wisconsin Academy of Sciences, Arts and Letters*; these were later reissued as one collection (Wisconsin Conservation Department 1954). Topics covered included: topography and geology of the Lake Superior basin (Bean and Thomson 1944); vegetation of the watershed (Fassett 1944; Thomson 1945); a history of fishing (O'Donnell 1944); a survey of the aquatic plants and bank flora (Thomson 1944); parasites found on fishes (Fischthal 1945); results of a four-year creel census (O'Donnell 1945); bottom sediments (Evans 1945); biology of the northern brook lamprey, *Ichthyomyzon fossor* (Churchill 1945); and physical, chemical, and biological attributes of the river as habitat for trout (O'Donnell and Churchill 1954). In 1946, a brief summary of fishery recommendations emerged which constituted the first WDNR management plan for the river. Recommendations included stocking guidelines, public acquisition of the Cedar Island spring ponds, an extended autumn season on the lower river, initiation of creel and trout population surveys, and several riparian protection and erosion control measures.

Early efforts by the WDNR to sample fishes using weirs occurred at Stone's Bridge and near the WDNR Ranger Station in 1943 (O'Donnell and Churchill 1954) and again at Stone's Bridge in 1958–60 (Fallis and Niemuth 1962). During 1961–64, intensive investigations of the anadromous brown trout and steelhead populations by the WDNR (Niemuth 1967, 1970) provided the first substantial data set from which management applications could be drawn. Field work included operation of fish weirs with two-way traps during much of the open-water seasons, electrofishing sampling of some mainstem reaches using mark/recapture techniques to obtain population estimates, and documenting upper river spawning sites. The weir locations were initially below Winneboujou and later just north of U.S. Highway 2. A similar investigation was repeated in 1978–79 (Scholl et al. 1984). This study also included electrofishing surveys of several Brule River tributaries. From 1957 to 1979 the U.S. Fish and Wildlife Service (USFWS) operated an electrical weir one mile above the mouth of the river in an effort to control spawning of sea lamprey. However, in the later years of its use, the TFM (3-trifluoromethyl-4-nitrophenol) lampricide program had been developed, and this weir served primarily to monitor the effectiveness of chemical control. Some data on anadromous salmonid populations were obtained from the operation of this weir (Scholl et al. 1984); however, its operation caused an increased incidence of spinal deformities to the salmonid populations as the downstream-migrating smolts passed through the electric field (Devore and Eaton 1983) and may have contributed to mortality of adult spawners as well. Unfortunately, reliable quantitative information about the salmonid populations was difficult to obtain from any of the fish weirs because of malfunctions caused by high water or vandalism during portions of virtually every operating season.

Studies by two University of Wisconsin–Madison graduate students also added to knowledge about Brule River trout. Hunt (1965) studied the importance of surface-drift insects in the trout diet, and Salli (1962, 1974) reported on the early life history of trout species in the lakes sector[3] (Fig. 1).

Efforts to assess the sport fishery were made in 1936, 1940, and in 1943–44 (O'Donnell 1945); in 1948–49 (Brasch 1950); in 1954 (Daly 1954); in 1962–64 (Niemuth 1970); in 1973 (Swanson 1974); in 1978–79 (Scholl et al. 1984); and in 1984, 1986, 1990, and 1992 (this report). Some of these were partial surveys with limited objectives, while others were intended to be comprehensive surveys of the river's mainstem. However, the size of the river, difficulty of access to some areas, and multiple uses by the public (which can render car and canoe counts unreliable as indicators of pressure), have created difficulties in obtaining reliable estimates of total angling pressure and harvest. Furthermore, comparisons among surveys are difficult because of changing open seasons, daily bag limits, size limits, stocking policies, and survey techniques over time. Results show that angling pressure on the upper river has remained fairly stable during recent years, but pressure has decreased on the lower river since the late 1970s (Table 3). On the upper river, catch rates have increased in recent years, while harvest has declined because of more restrictive regulations and an increased tendency by fly-fishers to voluntary release their catch (Table 3). On the lower river, catch rates have remained fairly stable or declined, while harvest of steelhead and brown trout have declined substantially (Table 3).

The WDNR Bureau of Research initiated a two-year pilot research study in 1983, which was followed by a long-term research initiative (1986–93). Both were carried out jointly with the WDNR Bureau of Fisheries Management. Topics addressed during this research, and the reporting status of the studies, are described in Table 4. This cooperative effort, in conjunction with direction supplied by the Brule River Committee, has contributed to improved management of the Brule River ecosystem.

History of the Fish Community

At least 63 fish species, including 11 exotic species plus one cultured hybrid, have been collected from the Brule River system (Table 1). Important shifts in the fish community from the historical condition have unquestionably occurred. These shifts appear to be primarily related to establishment of exotic species (additions of exotics or reductions in populations of native species attributable to sea lamprey control), although the loss of coaster brook trout could be attributed to over-exploitation or blockage of migration routes. Many species have not experienced demonstrable changes in their populations over the last 50 years, suggesting little (if any) change in habitat conditions. These conclusions were reached through a comparison of the fish fauna of 1987–91 with that described from surveys done during the mid-1940s (O'Donnell and Churchill 1954). However, the comparison is valid only for common species because of differences in equipment, survey techniques, and survey effort between the two time periods. Early surveys were less intensive than surveys done from 1987–91, and early electrofishing gear was less efficient. Hence, we have assumed that uncommon species not reported by O'Donnell and Churchill (1954) were missed by their sampling (as opposed to not being present).

Among the lampreys (Petromyzontidae) the differences between time periods are striking, with two species of native lampreys suffering from greatly reduced distributions and population densities. Northern brook lamprey were abundant in the 1940s (Churchill 1945), but we found no specimens during electrofishing surveys in the Brule River system in recent years. Silver lamprey (*Ichthyomyzon unicuspis*) were once plentiful in the lower river (McLain et al. 1965), but only a few specimens were found there in the 1970s (Schuldt and Goold 1980). The only silver lamprey we have seen in the Brule River was a specimen attached to a migratory brown trout that could have originated elsewhere. Using specialized gear and techniques developed for sampling lampreys, USFWS personnel have collected three adult northern brook lampreys from one mainstem area and Minnesuing Creek over the last thirty years (J. Heinrich, USFWS, pers. comm.). They have also collected moderate numbers of ammocoetes of *Ichthyomyzon* from Minnesuing Creek and the upper section of Nebagamon Creek, as well as small numbers of specimens from scattered mainstem areas. These specimens could be northern brook lamprey, silver lamprey, or some combination of the two. (It is not presently possible to identify *Ichthyomyzon* ammocoetes to species.) These species were seriously impacted by lampricide treatments aimed at controlling the sea lamprey (Table 1 – see also section on the sea lamprey and the effects of control efforts). Sea lamprey are now common downstream of the barrier/fishway, but were not yet established in the 1940s.

The most common minnow species (Cyprinidae) do not appear to have changed in either relative abundances or distributions since the 1940s. A number of occasional, uncommon, or rare species reported here (Table 1) were not reported by O'Donnell and Churchill (1954), but this difference is attributed to less efficient sampling during the 1940s. Shifts in population distributions of two less-common minnow species may have occurred. The northern redbelly dace (*Phoxinus eos*) occurred in the upper part of the mainstem in the 1940s, but in 1987–91 was confined to the lower river and tributaries. Similarly, the common shiner (*Luxilus cornutus*) was found in deeper sections of the upper river in the 1940s, but we found it only in the lower river below the barrier/fishway.

Among the salmonids no major changes in distributions of brook trout or steelhead between time periods were apparent. Brown

Table 3. Angling pressure, catch, and harvest statistics for upper and lower sections meaningful comparisons). Steelhead throughout the river system and brown trout from marily of anadromous adults, whereas the < 13" categories are primarily stream-resi- (reported in the "all brown trout" category only).

	Lower River				
Category	*1973*	*1978–79*	*1984*	*1986*	*1990*
Angling Pressure					
Trips per Mile	n/a	1,440	1,183	887	739
Hours per Mile	n/a	5,314	4,365	3,274	2,726
Total Hours	n/a	132,847	109,122	81,856	68,140
Catch per Hour					
Brook Trout	n/a	n/a	0.007	0.009	0.002
Steelhead (≥ 13")	n/a	n/a	n/a	0.030	n/a
Steelhead (< 13")	n/a	n/a	n/a	0.037	n/a
Steelhead (all)	n/a	n/a	0.098	0.067	0.100
Brown Trout (≥ 13")	n/a	n/a	n/a	0.007	n/a
Brown Trout (< 13")	n/a	n/a	n/a	0.013	n/a
Brown Trout (all)	n/a	n/a	0.015	0.020	0.004
Pacific Salmon	n/a	n/a	0.001	0.005	0.002
All Species	n/a	n/a	0.121	0.101	0.108
Harvest per Hour					
Brook Trout	n/a	n/a	0.004	0.007	0.002
Steelhead (≥ 13")	n/a	0.056	0.033	0.019	n/a
Steelhead (< 13")	n/a	0.027	0.002	0.007	n/a
Steelhead (all)	n/a	0.083	0.035	0.026	0.032
Brown Trout (≥ 13")	n/a	0.003	0.002	0.004	n/a
Brown Trout (< 13")	n/a	0.004	0.008	0.003	n/a
Brown Trout (all)	n/a	0.007	0.010	0.007	0.001
Pacific Salmon	n/a	n/a	0.001	0.005	0.002
All Species	n/a	n/a	0.050	0.045	0.037
Harvest per Mile					
Brook Trout	1.8	n/a	15.5	21.4	4.8
Steelhead (≥ 13")	189.0	299.6	143.5	63.8	n/a
Steelhead (< 13")	89.0	141.0	10.0	22.7	n/a
Steelhead (all)	278.0	440.6	153.5	86.5	86.4
Brown Trout (≥ 13")	16.5	17.7	9.7	14.7	n/a
Brown Trout (< 13")	8.4	19.7	36.6	9.4	n/a
Brown Trout (all)	24.9	37.4	46.3	24.1	4.1
Pacific Salmon	4.2	n/a	4.2	17.7	4.6
All Species	308.9	n/a	219.5	149.7	99.9

[1]See section on regulations for daily bag and size limits in effect during each survey year; sampling periods for the surveys included the entire regular open seasons on the upper river in 1973, 1984, 1986, and 1992, and the regular open seasons plus extended early and late seasons on the lower river in 1973, 1984, 1986. In 1990 the survey period on the lower river coincided with the spring and autumn anadromous salmonid runs and was not extended through the summer; also sampled was the time interval 1 July 1978 – 30 June 1979 during the regular and extended seasons on the upper and lower sections of river.

of the Bois Brule River since 1973[1] (n/a = data not available or insufficient to provide
the lower river are reported in two categories; the ≥13" categories are comprised pri-
dent or juvenile anadromous forms. This distinction is invalid for upper river brown trout

Upper River				
1973	*1978–79*	*1984*	*1986*	*1992*
n/a	284	436	297	310
n/a	1,354	2,081	1,414	1,482
n/a	17,599	27,054	20,108	19,271
n/a	n/a	0.208	0.296	0.650
n/a	n/a	n/a	0.004	0.018
n/a	n/a	n/a	0.195	0.190
n/a	n/a	0.097	0.199	0.208
—	—	—	—	—
—	—	—	—	—
n/a	n/a	0.057	0.067	0.149
n/a	n/a	0.002	0.007	0.021
n/a	n/a	0.364	0.568	1.028
n/a	n/a	0.105	0.095	0.059
n/a	0.014	0.001	0.001	0.006
n/a	0.026	0.028	0.021	0.001
n/a	0.040	0.029	0.022	0.007
—	—	—	—	—
—	—	—	—	—
n/a	0.043	0.032	0.037	0.022
n/a	n/a	0	0.005	0.002
n/a	n/a	0.166	0.159	0.090
73.6	n/a	218.7	147.2	88.2
4.1	19.5	2.0	1.4	8.8
148.8	34.5	58.8	32.6	0.8
152.9	54.0	60.8	34.0	9.6
—	—	—	—	—
—	—	—	—	—
66.9	58.6	66.1	56.8	33.2
0	n/a	0	7.2	2.3
293.4	n/a	345.6	245.2	133.3

Table 4. Topics addressed during the 1984–93 research initiative

Topic	*Reporting Status*
A bibliography of fishery-related references	DuBois 1989
Fecundity of steelhead from western Lake Superior	DuBois et al. 1989
Annual monitoring of adult anadromous salmonid run sizes, age structure, and migration timing using a fish trap at the lamprey barrier	file data in the WDNR Superior Office (D. Pratt contact) will be formally reported at a later date
Investigation of density, biomass, age and growth, and species composition of stream-resident and juvenile anadromous salmonids within discrete habitat zones	DuBois et al. in press
Sampling wild salmonid smolts	DuBois et al. 1991; other reports in preparation
Experiment to determine the effectiveness of planting hatchery-reared steelhead smolts of Brule River origin	file data in the WDNR Superior Office (D. Pratt contact), file report forthcoming
Evaluation of recent and historical habitat improvement efforts	DuBois and Schram 1993; this report summarizes all efforts to date
Creel surveys done in 1984, 1986, 1990, and 1992	unpublished file report in preparation; this report
Status of the aquatic insect community	DuBois 1993; DuBois and Rackouski 1992
The effects of lampricide treatments on the salmonids and their aquatic invertebrate food source	DuBois and Plaster 1993; DuBois and Blust 1994

trout were reported to be most abundant in the lower half of the river system in the 1940s (O'Donnell and Churchill 1954); however, based on the habitat needs and present distribution of this species we doubt this observation was accurately recorded. More recently, brown trout have been most common in the middle and upper reaches of the river. Populations of Pacific salmon have become established only since the early 1970s. Among the Esocidae, the northern pike (*Esox lucius*) was reported as being moderately common in some upper river areas (O'Donnell and Churchill 1954), whereas we encountered them only rarely from 1987–91. However, we did not effectively sample the areas having the best habitat conditions for northern pike (the lakes section[3]). The reasons for these apparent population shifts are unknown, but do not seem to be habitat-related.

Exotic species have changed the complexion of the fish community of the Brule River in major ways. Exotic salmonids have diversified the predator complex and, consequently, the angling opportunities. These salmonids gained access either through deliberate introductions to the river itself (brown trout, steelhead) or to other Lake Superior areas (Atlantic salmon [*Salmo salar*], chinook salmon, coho salmon, pink salmon [*Oncorhynchus gorbuscha*]). Other species gained access to the river unintentionally through a variety of avenues including the opening of the St. Lawrence Seaway via the Welland Canal (sea lamprey, American eel [*Anguilla rostrata*]), population expansion from introductions to connecting waters of the Great Lakes (rainbow smelt [*Osmerus mordax*], common carp [*Cyprinus carpio*]), or from the release of ballast water from transoceanic vessels in the Duluth/Superior harbor (ruffe [*Gymnocephalus cernuus*], Pratt et al. 1992). The establishment of exotic species in the Brule River has had mixed effects that have sometimes been difficult to assess, with some additions regarded positively (the salmonids), but others causing concern. For example, the sea lamprey has been the focus of expensive control efforts in Lake Superior tributaries for over thirty years, and the ruffe, while viewed as a limited threat to the Brule River ecosystem, may ultimately warrant control efforts in some areas of Lake Superior.

Of 52 native species, only 21 (40%) are primary riverine species with viable populations in lotic areas. The remainder are species that either are primarily found in the lentic habitats of Lakes Nebagamon and Minnesuing, are residents of Lake Superior that occasionally move into the lowest section of the lower river, or are locally rare forms that stray into the river. The longnose gar (*Lepisosteus osseus*), collected once from the river (Table 1), is at the northern periphery of its range in Lake Superior. Lake sturgeon (*Acipenser fulvescens*) have not been reported from the Brule River, but may have entered it historically since they are present in western Lake Superior and are known from nearby rivers. Arctic grayling (*Thymallus arcticus*) were not mentioned in any of the early accounts about the Brule River, but a population (now extinct) existed in Michigan waters of Lakes Superior, Michigan, and Huron (Scott and Crossman 1973). Therefore, Arctic grayling could have strayed into the Brule River, and they are mentioned along with brook trout in regulations pertaining to the river in the early 1890s.

Because the salmonids and the sea lamprey have received the majority of research and management attention, their life histories and interactions in the Brule River ecosystem are described in more detail in the remainder of this section.

Brook Trout

Reports of tremendous fishing for brook trout in the Brule River abound, particularly for the period 1830–1900 (O'Donnell 1944; Holbrook 1949; Marshall 1954). Historical records of angling catches can be unreliable, and must therefore be interpreted cautiously, but the consistency of the early angling records pertaining to brook trout is impressive (summarized by O'Donnell 1944). For example, a U.S. Infantry Lieutenant wrote in 1831 that "the river is exceedingly clear and cold and is filled with thousands of real mountain brook trout." And in 1846, a geologist charting the region in the interest of mining companies wrote, "It surpasses all other streams in its brook trout, some of them, . . . weighing ten pounds. Its waters colder and clearer, if possible than any other river."

The only salmonid native to the Brule River, brook trout sometimes grew to a large size with reports of 6- to 10-pound fish not uncommon (O'Donnell 1944). That a part of the original brook trout population was of the coaster variety is virtually certain (O'Donnell 1944). This conclusion is consistent with historical information about the life history of brook trout in other Lake Superior tributaries (Bullen 1988). Coasters appear to have been common along the south shore of Lake Superior during the 1800s (Shiras 1935), and the Brule River may have been a major producer.

However, by the 1870s evidence of public concern about overharvest of brook trout in the region was beginning to surface. A quote from the *Superior Times* (February 24, 1876) is illustrative: "while our legislature is devoting time and money to the propagation of fish within the state it is a pity they do not stop the wholesale slaughter of brook trout through the ice in the Lake Superior counties." By the early 1890s, the Brule River brook trout fishery had begun to decline (O'Donnell 1944). Excessive angling catches undoubtedly occurred frequently during the late 1800s and early 1900s as regulation of recreational angling was very liberal with no daily bag in effect until 1905 (see section on regulation of the fishery). This history of substantial and at times excessive harvest has continued to the present as increases in angling pressure have accompanied increasing harvest restrictions. Hence, over-exploitation is a major factor implicated in the reduction of the brook trout population.

Lumber interests started cutting the virgin timber in the Brule Valley in 1892, and the logging dams they built allegedly damaged the coaster population by blocking their migration route at critical times (O'Donnell 1944). A law was on the books at that time requiring a fishway at any dam or obstruction on the Brule River (Chapter 251, Laws of 1891). Unfortunately, noncompliance was rife, and a 1906 article (quoted by O'Donnell 1944) explicitly states that there were no fishways at the logging dams on the Brule River. Siltation associated with poor forestry practices likely also contributed to the decline of the fishery (Holbrook 1949; Marshall 1954). Interspecific competition with heavily stocked brown trout and rainbow trout during the 1920s and 1930s may have also negatively affected the brook trout population. Coaster brook trout were apparently extirpated from the river by the mid-1940s, with the latest reliable record being of a 24-inch fish observed spawning in the upper river in 1944 (O'Donnell and Churchill 1954).

Efforts to bolster the sagging brook trout fishery included supplemental stocking of domestic strains, which began in 1894 and continued steadily for over 80 years, and introductions of exotic species (early plantings summarized by O'Donnell 1945). Stocking of brook trout was terminated in 1979 because of emerging evidence from the fisheries literature, now even more firmly established, that stocking domestic strains of trout on top of healthy wild populations often has more negative than positive effects (White 1989; Goodman 1990). This represented a major change in management policy which may have contributed to some recent recovery of the brook trout population.

Early records about the strains of brook trout stocked in the Brule River are sketchy, and undocumented plantings by wealthy private citizens or citizen groups may have occurred. Domestic brook trout strains, which have been systematically selected from fast-growing, early-maturing brood stocks, can have a significant reproductive advantage over wild fish. Gene flow from these strains may have altered, to an unknown degree, the genetic structure of the original brook trout population, which was uniquely adapted to the physical setting of the river.

The present brook trout population is largely confined to the upper (southern) half of the river and most of the tributaries (Fig. 2) where ice-free conditions for long stretches during winter provide evidence of abundant spring flow. They exist sympatrically with populations of exotic salmonids

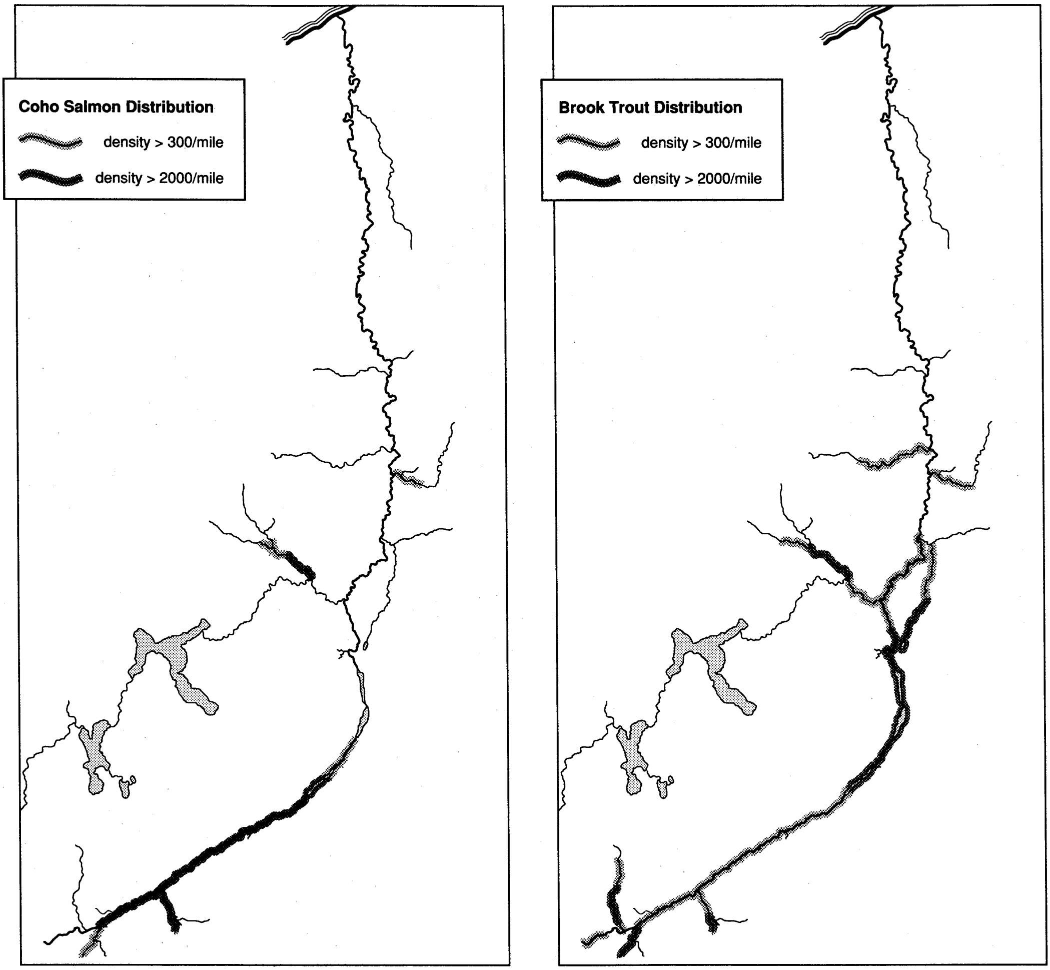

Fig. 2. Present distribution of juvenile coho salmon and brook trout of all age classes in the Bois Brule River system showing areas of highest population density

in sufficient numbers and sizes to provide acceptable fishing. The Brule River contains the largest population of brook trout of all Wisconsin streams draining into Lake Superior. However, they are the least abundant of the three primary salmonid species in the Brule River system (DuBois et al. in press). Brook trout spawn in slower-flow areas, often near springs where small-sized gravel and the upwelling ground water conditions they require are suitable. Spawning areas in the Brule River have not been well documented, but are probably scattered widely throughout the upper river and several tributaries in spring pond areas and other areas of reduced flow. Spawning likely could be enhanced by dredging spring pond areas adjacent to the main channel along the upper river (Carline 1980).

Steelhead

Steelhead were first introduced to the Brule River in 1892 (O'Donnell 1944), and stocking of a variety of Pacific Coast strains continued periodically through 1981 (see

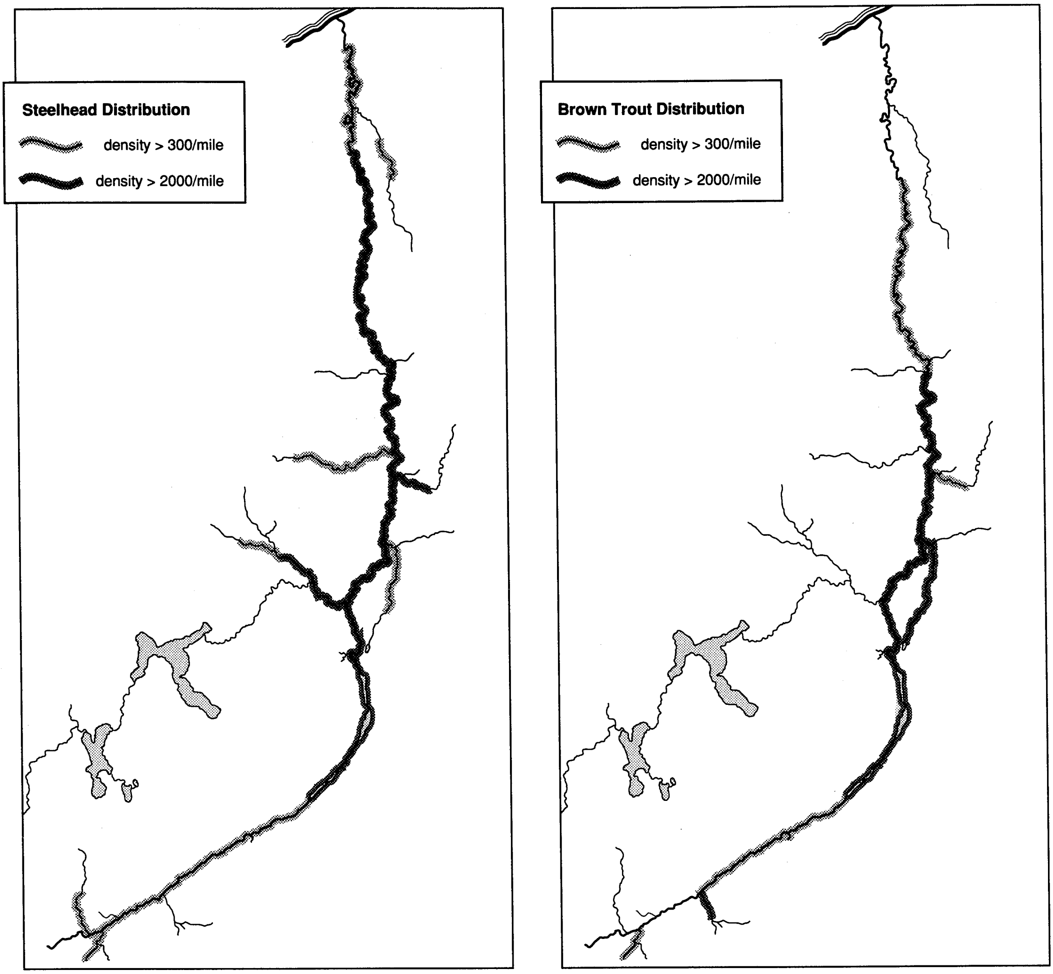

Fig. 3. Present distribution of juvenile steelhead and brown trout of all age classes in the Bois Brule River system showing areas of highest population density

MacCrimmon and Gots 1972, and Krueger and May 1987a). Steelhead have become the most abundant salmonid in the river system (DuBois et al. in press). This species has a strong migratory tendency, and it appears that the entire Brule River population is anadromous, although this apparently was not the case originally (O'Donnell 1944). Steelhead inhabit most of the river system as juveniles (Fig. 3), but descend into Lake Superior as smolts after one, two (usually), or three summers in the river. Once in the lake, these fish grow to a large size and then return to the river to spawn after one, two, or three more years. Upon reaching maturity they spawn annually (Swanson 1985), with a few spawning every other year (Seelbach 1993).

About 15 major spawning areas used by steelhead were identified by O'Donnell and Churchill (1954) and Niemuth (1967, 1970) in riffle areas between Stone's Bridge and Winneboujou. Spawning in the lower river is even more significant, but it is more diffi-

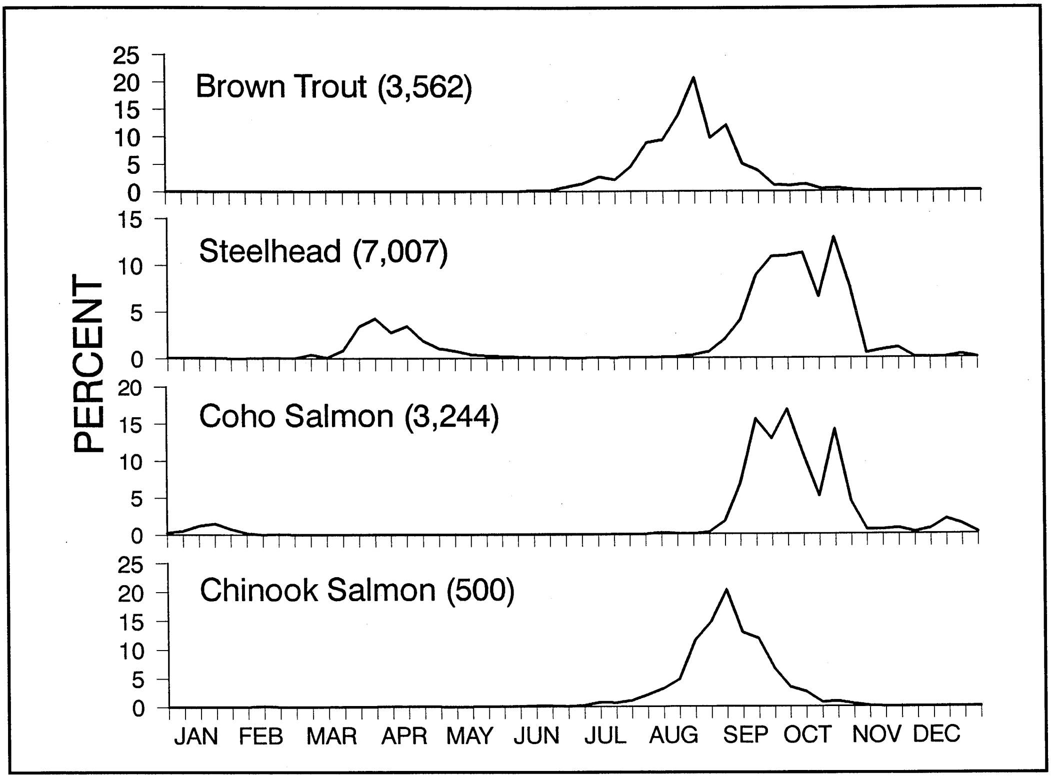

Fig. 4. Five-year (1989–93) mean weekly distribution of anadromous salmonids ascending the Bois Brule River on annual spawning runs (mean number per year for each species during 1989–93 in parentheses)

cult to document the specific locations used and hatching success because of higher turbidity and deeper water. Year-class strength of juvenile steelhead has been stable in the upper river, but highly variable in the lower river (DuBois et al. in press). This variation has apparently resulted largely from environmental factors and may not be closely related to numbers of spawning adults. The lower river is less stable than the upper river in terms of both its flow and temperature regimes. We speculate that a critical factor associated with year-class strength in the lower river pertains to spring flooding, which may have a devastating effect on eggs and newly hatched fry (Seegrist and Gard 1972). The limited data available suggest that when there is little flooding in the spring when the young-of-the-year are small (less than about 2 inches), survival is high. Also, during warm springs, growth is faster, allowing young fish to grow more quickly through the critical "window of time" when they are vulnerable to spring flooding.

Though all steelhead spawning apparently occurs in the spring (some autumn spawning is possible but unlikely), two distinct migration patterns have emerged: a larger autumn run of fish ascends the river from September through December and overwinters in deeper holes throughout the mainstem of the river, and a smaller spring run begins to ascend the river in February or early March and continues through May

(Fig. 4). A study to investigate the possible genetic distinctness of these runs did not show significant differences (Krueger and May 1987a). It is therefore probable that the autumn and spring spawning runs are actually one extended run interrupted by a temperature-related cessation of migration cues during winter. The large autumn run on the Brule River is unique among Wisconsin's tributaries to Lake Superior, the others having substantial spring runs and only small autumn runs (if any). The reason(s) for this difference among streams is not clearly understood, but the availability of suitable overwinter holding areas in the Brule River, the relative seasonal stability of its flow, and the moderated thermal regime that contributes to its becoming ice-free earlier in the spring than most other streams, may all be important factors.

Evidence mounted during the early and mid-1980s that the steelhead population of the Brule River had declined disturbingly since the late 1970s and may now be at only a small fraction of its former abundance. For example, the estimated steelhead harvest during 1978–79 (about 7,000) was roughly similar in magnitude to the estimates of the entire run sizes in recent years (Fig. 4). Other tributaries along Wisconsin's Lake Superior shoreline showed a similar pattern of declining runs since the 1970s suggesting that the western Lake Superior steelhead stocks were collectively declining and may have been approaching a collapse (B. Swanson, WDNR, pers. comm.). Causes of this decline (which unfortunately coincided with a year-round open season on the Brule River during 1983–85) were unknown, but overharvest in Lake Superior as well as in the streams was strongly suspected.

In response to this perceived threat to the steelhead stocks, the WDNR enacted more restrictive size and bag limit regulations in 1989, and embarked on a limited-term steelhead stocking experiment for the Brule River to bolster its population. The stocking plan called for an annual egg-take operation (about 100,000 eggs annually) from wild Brule River steelhead and subsequently raising these juveniles to smolt size (approaching or exceeding 7 1/2 inches). The goal of the stocking program was to release 50,000 functional smolts at various locations on the lower river each May until the program was no longer needed. Anglers have also responded by practicing more catch-and-release angling for steelhead on a voluntary basis (D. Pratt, unpubl. data). In 1993, the minimum legal size was further increased to 26 inches to allow maiden spawners to spawn at least once before entering the harvest (see section on regulations for complete description of steelhead sport harvest restrictions). At least several years will be required to assess the effectiveness of these measures. The wisest course of action for steelhead is to manage with conservative regulations; however, highly variable year-class strength related to environmental factors outside of management control will lead to large variations in annual angling quality, regardless of best management practices. Additional descriptive aspects of the Brule River steelhead population have been reported by Niemuth (1970) and Scholl et al. (1984).

Brown Trout

Brown trout were introduced to the Brule River by the WCC in 1920 (O'Donnell 1945). However, they may have already become established in the river from stockings elsewhere in the Lake Superior basin (Krueger and May 1987b). Many domestic strains of brown trout were undoubtedly stocked before stocking of this species was terminated in 1974. A self-sustaining population of brown trout developed early on, and they are now common throughout much of the river system (Fig. 3).

Two ecologically distinct groups of autumn-spawning brown trout coexist: a stream-resident component provides a challenging upper-river fishery and an anadromous (lake-run) component exhibits a life history strategy similar to steelhead. Anadromous brown trout spawning runs begin in July, peak in August, and extend into October (Fig. 4). Juveniles reside in the river for one (usually), two, or rarely three years before smolting in the spring or autumn. They then usually spend two years in the lake before returning to the river to spawn at age three or four. Although spawning need not result in the death of brown trout in an obligatory sense, as is the case with Pacific salmon, repeat spawning is relatively uncommon, and high natural mortality appears to be associated with spawning.

Brown trout sampled from western Lake Superior tributaries were found to differ genetically among drainages, between anadromous and stream-resident life histories, and among locations within the Brule River drainage (Krueger and May 1987b). Anadromous brown trout provide a rare trophy fishery, but have been generally less popular than steelhead because they are often harder to catch. Additionally, they are susceptible to mortality from furunculosis, caused by the bacterium *Aeromonas salmonicida*. Some fish carry the disease without symptoms, but outbreaks of furunculosis have sometimes reached epidemic proportions in the Brule River. Although furunculosis was observed prior to intensive weir study (Niemuth 1967), stress associated with handling large numbers of brown trout at weirs may have aggravated the prevalence of the disease. Warm river temperatures in August when most anadromous brown trout ascend the river have also been implicated in activating symptoms.

Resident and anadromous brown trout spawn in many of the same mainstem areas used by steelhead, but are more spatially restricted than steelhead in the lower river and the tributaries. This restriction may be related to the difficulty posed for overwintering eggs by anchor ice in the less-thermally-moderated lower river and by typically lower water levels in the tributaries during their autumn-spawning period. Information on size and age structures and other descriptive aspects of the anadromous brown trout stocks have been reported by Niemuth (1967) and Scholl et al. (1984).

Pacific Salmon

Three species of Pacific salmon have been found in the Brule River in recent years; all are strays from stockings by neighboring states and the Province of Ontario. Their sudden appearance serves as a reminder that the Brule River is not an isolated system, but rather, is intimately tied to the ecology of the surrounding region. Scott and Crossman (1973) described the life histories of Pacific salmon in the Great Lakes, and Scholl et al. (1984) provided early information about the population characteristics of these autumn-spawning species in the Brule River.

First documented in the Brule River in 1973, coho salmon have established a viable though widely fluctuating population. Their life history strategy involves one year of stream residency for juveniles, outmigration as smolts in May, and growth in the lake for one or two years before returning to the stream to spawn and die. Adults have contributed significantly to the sport catch in recent years. Coho salmon have so far shown a three-year cycle of abundance in the order of a small-run year, an intermediate year, and a large-run year. Numbers of spawners and the resulting young are strongly correlated. Spawning runs have peaked in mid to late September, but substantial movement has occurred throughout autumn and extended into winter (Fig. 4). Coho salmon spawn successfully throughout the upper river and tributaries, favoring smaller riffles near headwater areas (Fig. 2). Juveniles fare well in the slow, deep, alder-choked sections of the upper river south of Stone's Bridge; because these areas are extensive, the Brule River will likely remain a strong coho salmon producer.

Establishment of a viable chinook salmon population has developed more slowly than that of the coho salmon, although the first adults were also documented in 1973. During the late 1970s and early 1980s, small numbers of juveniles were found only in Blueberry and Nebagamon creeks and in mainstem riffles close to the confluence with Nebagamon Creek (Fig. 1). Since 1988, chinook salmon have spawned over a slightly wider range of locations, although still centered in the same general area. Year-class strength has also shown modest increases (DuBois et al. in press). Chinook salmon in the Brule River smolt mostly as young-of-the-year in May and June, with the remainder smolting during autumn or the following April/May. After smolting, chinook salmon spend up to five years in the lake (four years is most common) before returning to the river to spawn. Spawning runs, which have peaked from mid-August through September (Fig. 4), have contained modest numbers of spawners; the extent to which their population size or distribution may change is unknown.

Pink salmon have also been found in the Brule River, although not in appreciable numbers since 1979 (Scholl et al. 1984). Their potential for establishment in the Brule River appears limited.

The Sea Lamprey and Effects of Control Programs on Other Fishes

Sea lamprey were introduced to the upper Great Lakes through the opening of the Welland Canal and were first reported in Lake Superior in 1938 (Becker 1983). Although early records of their spawning in the Brule River are sketchy, they had developed a viable population in western Lake Superior by the mid-1950s. Primary spawning areas in the Brule River are not well known but likely included both mainstem and tributary riffles near silt beds for ammocoete habitat. Sea lampreys quickly caused serious damage to the salmonid populations of Lake Superior (National Research Council of Canada 1985). The Brule River was one of the largest tributary producers of sea lampreys in the Lake Superior basin, yielding approximately one-third of the entire catch from Lake Superior streams (McLain et al. 1965). Beginning in the mid-1950s, control programs initiated by the USFWS began to dramatically reduce sea lamprey recruitment to Lake Superior by disrupting their spawning and larval phases through use of mechanical weirs, electrical weirs, and later, selective lampricide treatments (Smith and Tibbles 1980). In the Brule River, sea lamprey control has included an electrical weir one mile upstream from the mouth of the river from 1957 through 1979, selective lampricide treatments using TFM at three-year intervals in the entire mainstem and throughout most of the tributaries from 1959 through 1986, and a mechanical barrier used in conjunction with chemical treatment only below the barrier since 1986.

Although TFM treatments of the Brule River successfully reduced sea lamprey recruitment, deleterious effects on some non-target organisms were observed, and the monetary cost of treatments was high

(Gilderhus and Johnson 1980). Concern about these negative aspects led to the construction in 1984 of a sea lamprey barrier, located about seven miles upstream from the mouth of the river (Fig. 1). Initially, a low-head dam with jumping pools to allow migratory salmonids to pass upriver was built. However, this structure did not pass salmonids during all water conditions, and plans for remodeling were formulated. A reconstruction, including an effective fishway, was begun in 1985 and completed in March of 1986. The fishway included a viewing window which has proven to be a valuable research tool to obtain data on salmonid run numbers and other population statistics. This barrier system functions via use of a low-head dam with an overhanging metal lip within the fishway of a height surmountable by leaping salmonids but insurmountable to sea lampreys. The primary barrier which crosses the entire width of the river is higher than the fishway barrier and is impassable by all sea lampreys and most migratory salmonids. During autumn when no sea lamprey movement occurs, the fishway barrier is removed, allowing free upstream access to all fish species. The USFWS will periodically monitor the entire river and tributaries for presence of ammocoetes to determine any need for further treatment of upriver areas. Because the barrier appears to stop all sea lamprey movement, routine TFM treatments will now be made only downstream of it. Sections of the Brule River above the sea lamprey barrier were last treated in 1986 to kill ammocoetes produced before its completion.

All species of lampreys are highly sensitive to TFM, and populations of three species of endemic lampreys have been greatly reduced or eliminated from treated streams within the Lake Superior basin (Schuldt and Goold 1980). In the Brule River, the silver lamprey and the northern brook lamprey were once abundant, and their populations have been greatly reduced by repeated treatments (Table 1). It is not known if silver lamprey were historically indigenous to sections of the Brule River above the sea lamprey barrier.

Other groups of aquatic organisms are affected to different degrees by TFM. Lampricide treatments usually have substantial negative effects on a relatively few forms of invertebrate life (Gilderhus and Johnson 1980; Dermott and Spence 1984; MacMahon et al. 1987), and they do not usually have severe direct effects on salmonid populations (Dahl and McDonald 1980). Secondary effects on salmonids due to a reduced invertebrate food supply also are unlikely to be severe (Merna 1985; DuBois and Blust 1994). However, other families of fishes, particularly ictalurids (catfishes) and catostomids (suckers), are quite sensitive to TFM. Stonecats (*Noturus flavus*) in the lower Brule River and in other western Lake Superior tributaries were so severely affected by TFM treatments that it was initially feared that they might have been eliminated from Lake Superior (Dahl and McDonald 1980). Fortunately, untreated refugia apparently existed for a portion of the stonecat population. Populations of other fishes indigenous to the Brule River may have been reduced because of TFM treatments. Dahl and McDonald (1980) provide a thorough discussion of the known effects of sea lamprey control on non-target fishes in the Great Lakes.

Control of sea lamprey spawning in the Brule River will remain an important fisheries management priority. Although research on alternative methods of sea lamprey control is ongoing, mechanical barriers and chemical treatments remain the most successful of the practical options.

Habitat Management

The history of the Brule River is dotted with numerous efforts to preserve the integrity of the physical habitat, enhance habitat for salmonids, and stabilize riparian areas. These efforts fall into five categories: (1) preservation of riparian areas, (2) in-stream habitat enhancements, (3) beaver control and dam removal, (4) bank stabilization in red clay areas subject to slippage, and (5) dredging projects.

Preservation Efforts

A major factor in the preservation of the Brule River ecosystem has been the protection afforded by state stewardship acquisition of land bordering the river. The Brule River State Forest was established in 1907 when Frederick Weyerhauser deeded 4,320 acres to the state. Land acquisition since has added to that total as funds have allowed. In 1959, the boundaries of the Brule Forest were extended to include the entire Brule River corridor. Presently about 40,000 acres of land are under state ownership, which represents about 80% of the total acreage within the boundary of the Brule River State Forest and includes about 50% of the river frontage (C. Zosel, WDNR, pers. comm.).

Another major factor contributing to preservation of the Brule River ecosystem has been the excellent stewardship practiced by private riparian landowners over many years (Holbrook 1949). Brule River Preservation, Inc., is a public nonprofit corporation including over 20 landowners from the upper river dedicated to preserving the Brule River and fostering sound ecological management for its use. The Nature Conservancy (TNC), an international organization dedicated to preserving unique natural areas, has a Conservation Easement Grant Program in effect on much of the upper river between Blue Spring and the WDNR Brule Area Headquarters (Fig. 1). This program features agreements between individual landowners and TNC whereby the landowners voluntarily restrict certain rights of use and development on their lands in perpetuity in order to ensure that these lands are protected against unwise commercial development and ecological degradation.

In-Stream Habitat Enhancement

The WDNR has been at the forefront nationally in the development of in-stream habitat enhancement techniques for salmonids. Consequently, much is now known about the identification of environmental deficiencies and the application of appropriate structural remedies to Wisconsin's streams (White and Brynildson 1967; Hunt 1988, 1993). Techniques used in the Brule River have included wing deflectors and bank covers, debrushing and installation of brush bundles, and removal of downed trees and other debris. Unfortunately, most of these efforts were undertaken before knowledge about effective techniques had been refined. A project of "stream improvement" was started in 1936 using Works Progress Administration labor. A total of 286 structures were installed in the river including deflectors, bank covers, and other stream enhancement devices, many of dubious value for creating trout habitat (O'Donnell 1944; Holbrook 1949; Marshall 1954). This effort appears to have been focused on making the river easier to canoe (O'Donnell 1944). Some of these structures still exist, either complete or as remnants, below County Highway P, below Stone's Bridge, in the Winneboujou area, and near the WDNR Area Headquarters. Additionally, the Civilian Conservation Corps installed structures, planted willows, and "clean[ed] out large amounts of down trees and other materials" at about the same time (O'Donnell 1944, p.29). The beneficial role of large, downed timber in shaping stream morphology and creating salmonid habitat has only been realized in recent decades (Harmon et al. 1986; Bisson et al. 1987). Current thinking now favors adding large woody debris to the stream to compensate for wood removed by earlier enhancement efforts or lost for other reasons[4]. During the 1960s, a series of rock deflectors was installed below the State Highway 13 bridge by the Brule River Sportsmen's Club, Inc. Also in the 1960s, the Douglas County fish and Game League (under cooperative agreement with the WDNR) constructed rock wing deflectors in several lower river locations to provide cover for salmonids and deflect current away from red clay banks. No follow-up evaluations were made of any of these early efforts.

Habitat enhancement efforts by the WDNR within the Brule River watershed since the 1960s have focused on riparian debrushing and installation of brush bundles on inside bends in some tributary areas choked with speckled alders (*Alnus rugosa*). Riparian debrushing lets sunlight into the stream for aquatic plant growth and encourages physical improvements in the stream channel, while brush bundles provide cover for trout fry and accelerate a favorable channel-constriction process (Hunt 1979). Such efforts on the East and West forks of the Brule River appear to have improved trout habitat, but were not evaluated to document their impact on trout populations. During 1978–91, a project on the Little Brule River below the state trout hatchery to remove all beaver dams and riparian alders and install brush bundles was conducted and evaluated (DuBois and Schram 1993). Natural reproduction in both treatment and control sections improved during the post-treatment period. However, numbers of legal-size brown trout declined markedly in both treatment and control sections following treatment, a result that could have been due to increased fishing pressure brought on by publicity surrounding the project, the improved fishability of the debrushed stream segment, or movement of large brown trout out of the stream.

Beaver Control and Dam Removal

Effects of beaver dams on trout habitat have generally been regarded as negative in Wisconsin although they are considered beneficial in small, high-gradient streams. Negative effects are most likely to occur on streams of low-to-moderate gradient where dams may contribute to warming of water, hinder salmonid movement and spawning, cause silting-in of gravel areas important for producing insects, and produce poor channel characteristics (summarized by Avery 1983). Traditionally, beaver have been regulated by trapping because of the value of their fur. For example, heavy trapping of beaver on the Brule River in 1803–04 drastically reduced their numbers (Marshall 1954). However, beavers are prolific, and animals from surrounding areas tend to recolonize trapped-out areas, creating an unceasing cycle. Furthermore, intensity of trapping effort fluctuates because of unstable fur prices. Recent low fur prices and excellent habitat have resulted in a large beaver population in northern Wisconsin. The Brule River and tributaries have been on various special extended beaver trapping seasons since the early 1960s, including a liberal open season since the mid-1980s. The Brule River watershed was included in a WDNR beaver subsidy program from 1986–88 that provided a financial incentive for trappers to control populations in designated areas. Since then, a trapper from the Animal Plant Health Inspection Service of the U.S. Department of Agriculture has worked under WDNR direction to remove beaver from within the Brule River watershed and other salmonid tributaries to Lake Superior.

Beaver dams on the Brule River generally occur only in the upper river above Stone's Bridge and in several tributary areas. Although historically these were probably also the areas of heaviest beaver activity, dams may have occurred further downstream as well. Numerous recent excursions to remove beaver dams from the upper Brule River have been made by WDNR workers, members of area sports clubs, and other citizens, but results have been short-lived, especially if beaver were not also removed. A recent habitat development project on the Little Brule River evaluated the effects of beaver dam removal and riparian debrushing on the physical conditions of the stream channel and on the salmonid populations (DuBois and Schram 1993). Although physical changes in channel morphometry following these manipulations were impressive, salmonid population responses were mixed, and the beneficial aspects could not be attributed solely to dam removal.

Bank Stabilization

The clay soils in the Brule River watershed appear to be geologically young and undergoing a high rate of natural erosion. When Europeans settled in this area, their lumbering, road construction, and agricultural activities removed the established mixed-conifer forest cover type and altered drainage patterns in ways that accelerated this pattern of erosion. Present-day activities, although more carefully controlled, continue to aggravate the erosion process.

Erosion of the red clay soils of the lower Brule River Valley has the potential to negatively affect salmonid populations. The potentially most damaging effect is from sedimentation, which can inhibit aquatic invertebrate life and reduce salmonid spawning success by causing high egg and larval mortality. In extreme cases, turbidity can also reduce feeding success of visually feeding salmonids and inhibit proper gill function (Berg and Northcote 1985). However, turbidity is probably not an important limiting factor for salmonids in the lower Brule River because other tributaries to Lake Superior in Wisconsin are known to have longer-term turbidity episodes yet have contained robust salmonid populations in recent decades.

A red clay interagency committee was formed of state and federal agencies in 1955 to investigate land-use problems on the red clay soils of northwestern Wisconsin. The goals of this committee were to determine the causes of red clay sedimentation in area lakes and streams and to study means of erosion and sedimentation control. Experimental work to reduce clay erosion was done on the Brule River in a few areas using gabions and riprap to stabilize bank slippage. Some successes were achieved in areas of less extreme slippage, but the efforts were expensive and the results obtrusive in a natural setting. Various mulchings and plantings were also tried in localized areas. State forest management goals now call for specialized timber management in steeply sloped red clay areas, with the long-range objective of returning the area to mixed-conifer forest. This plan may eventually lead to reduced bank erosion and slippage, but decades will be required to assess the results.

Dredging Projects

Dredging of spring ponds in Wisconsin can benefit brook trout spawning (Carline 1980), but indiscriminate dredging of streams can produce harmful physical changes such as degradation of the streambed (headcutting) and bank erosion (Kanehl and Lyons 1992). Several dredging projects have been carried out on the Brule River with the goal of enhancing trout habitat by creating deeper pools and exposing gravel substrates for spawning and increased invertebrate production. In the late 1920s, the WDNR dredged the east side of Big Lake. Blue Spring and a short stretch of river above Stone's Bridge were dredged by a private interest in the late 1960s. These projects were never evaluated to document benefits that may have accrued. In 1967, Douglas County and the Douglas County Fish and Game League tried to deepen and straighten the mouth of the Brule River by dredging. The attempt was futile, however, as the river quickly reverted back to its original form.

Regulation of the Fishery

Restrictions on fishing on the Brule River have usually followed the regular statewide trout and salmon regulations, with various extended special seasons on the lower river. In the early 1900s the four northern counties bordering Lake Superior were sometimes subjected to different open seasons on trout than the rest of the state. The many changes occurring over the history of regulation in open season dates, daily bag limits, and minimum sizes are described below in chronological order.

Open Seasons

Regular Season. The first restriction on trout fishing enacted in Wisconsin was a reduction in the length of the statewide open season from 12 months to 8 months in 1858. In 1878, the open season was further reduced to 5 months. From 1891 through 1898 the open season on the Brule River was greatly reduced to just 26 days in August (Chapter 138, Laws of 1891). Reasons for this restriction were not stated, but we note its concurrence with the era of intensive logging and use of logging dams to transport logs downriver en masse; release of these dams would have created serious hazards for anglers downstream. The length of the open season has varied since, but has usually been between 4 and 5 months. The season opener has varied between mid-April and mid-May; the closing date for the regular season has also been variable, occurring sometime between August 20 and September 30.

Special Extended Seasons. Various extended seasons have been enacted for the lower river between U.S. Highway 2 and Lake Superior to allow increased angling opportunities during anadromous salmonid spawning runs. These seasons have included a special early season, starting in spring sometime prior to the regular season and running to the regular season opener, and a special late season, starting in autumn after the regular open season and extending for various periods of time. Season extensions began in 1935 with a special early season starting on May 1 (at that time the regular season opener was on May 15). The starting day for the special early season has since varied, but has most often been the Saturday nearest April 1. Special regulations for the autumn season began in 1954 with an extension through November 15 and a further extension to December 31 in 1974. In 1983, a year-round open season was created from U.S. Highway 2 to Lake Superior to spread out fishing pressure and create additional angling opportunities. This year-round season was rescinded after the 1985 season because of public dissatisfaction and indications of excessive harvest. Present season extensions run from the Saturday nearest April 1 through November 15.

Daily Bag and Minimum Size Restrictions Prior to 1989

There was no statewide restriction on the daily bag for trout until 1905 when it was set at not more than 10 pounds. In 1909, the daily bag was changed to 45 trout; it was subsequently reduced to 35 trout in 1917, 25 trout in 1923, 15 trout in 1929, and 10 trout in 1949. From 1949 to 1989 the daily bag during the regular season remained at ten trout or salmon, sometimes with the stipulation that only five of those could be steelhead, or steelhead and brown trout in aggregate. Daily bag limits for the Brule River during the special extended seasons were more restrictive than during the regular seasons. From 1962 to 1989, the daily bag during the extended seasons was five trout or salmon in aggregate, with the stipulation for 16 of those years that only two of the five could be steelhead.

The first size limit enacted for trout in Wisconsin was a 6-inch minimum in 1905. In 1915 the statewide minimum length was increased to 7 inches; it was set back to 6 inches again in 1950, where it remained until 1989. The special extended seasons have been subject to higher minimum lengths, beginning with a 13-inch minimum for the late season in 1954. In 1970, the minimum length limit during the early and late seasons was reduced to 10 inches, where it remained until 1989.

Recent Changes in Daily Bag and Minimum Size Limits

Although anglers were increasingly practicing voluntary catch-and-release during the 1980s (Table 3), by 1989 it became apparent that additional restrictions on harvest of both adult spawners and presmolts of steelhead and brown trout were necessary to protect the fishery. Excessive harvest was strongly implicated in the declining numbers of spawning steelhead. Concern had also mounted that harvest of large, resident brown trout may have been dangerously high, especially during a popular, early-summer mayfly hatch (*Hexagenia limbata*) when trout are particularly vulnerable. An additional concern surfaced that harvest of presmolt steelhead and brown trout 6 to 10 inches in length may have been substantially reducing run sizes of adult spawners. Studies had shown smolt size to be positively correlated with survival to the maiden spawner stage (e.g. Ward and Slaney 1988), and that if steelhead survived their presmolt winter, they had an excellent chance to grow to trophy size (Seelbach 1987). Hence, larger presmolts were valuable and required protection from harvest.

New regulations in 1989 for the entire open season therefore included a reduced daily bag limit of five salmonids in total of which only one could be a steelhead 12 inches or larger and only two could be brown trout larger than 15 inches. Minimum sizes were increased to 10 inches on brown trout and 12 inches on steelhead and Pacific salmon to protect anadromous presmolts. The minimum size limit on brook trout was also increased to 8 inches to allow more fish to grow into a desirable size range. In 1993, the minimum size limit on steelhead was further increased to 26 inches for the Brule River and all other Wisconsin tributaries to Lake Superior to ensure that young adults would have the opportunity to spawn at least once before entering into the harvest. More time is needed to determine the extent to which these changes may have benefited the fishery.

Concurrent with the decline in the Brule River steelhead run in the mid and late 1980s were indications of reduced steelhead runs in other Wisconsin tributaries to Lake Superior (B. Swanson, WDNR, pers. comm.). Increasing harvest of steelhead in Lake Superior by anglers in charter and private boats was suspected of contributing substantially to this disturbing decline of steelhead in western Lake Superior. Hence, in 1990, regulations for the Wisconsin waters of Lake Superior were changed to allow daily harvest of only one steelhead over 28 inches in length.

Other Restrictions on Fishing

Gear restriction proposals for reducing harvest and post-release mortality of salmonids in sections of the upper river have periodically been voiced. However, the only gear restriction ever enacted was for "fly fishing only" for the stretch of river from Stone's Bridge to Winneboujou in 1938 in response to a petition by landowners. This restriction was rescinded shortly thereafter, following a storm of public protest that may have been politically generated (Holbrook 1949).

Other restrictions include no fishing from 1/2 hour after sunset to 1/2 hour before sunrise during the extended seasons on the lower river, and the establishment of small refuge areas closed to fishing where migrating fish tended to congregate and illegal snagging was known to have occurred (below the sea lamprey barrier, the Boxcar Hole and the Skid Mays area within the Ledges section[5]).

Voluntary catch-and-release is being practiced with increasing frequency, especially on the upper river, as the angling community re-evaluates the value it places on wild salmonids. Brule River Preservation, Inc., the Brule River Sportsmen's Club, Inc., and Trout Unlimited of Wisconsin have undertaken a collaborative signage project on the upper river that suggests the practice of voluntary catch-and-release to preserve good fishing. These types of voluntary initiatives have been shown to effectively shape angler behavior because many anglers are influenced by the ethics of their peers. Also, anglers are concerned about the future of their sport and typically respond well to education.

Management Implications

1. Continue the focus on riparian protection. A strong posture by the WDNR and private interests on protecting riparian areas has existed for decades and should continue. A healthy riparian zone is instrumental for maintaining water quality and instream habitat diversity, which are in turn critical for the continuing support of a diverse array of coldwater life. The state should continue its policy of land acquisition within State Forest boundaries from willing sellers where feasible. An enduring focus on cooperative ecosystem stewardship by riparian landowners, the Brule River Preservation, Inc., the Brule River Sportsmen's Club, Inc., and a broad range of WDNR functions will remain invaluable.

2. Focus for instream habitat maintenance and enhancement. Habitat maintenance and enhancement considerations for the river system should include beaver control and dam removal to maintain an unimpeded migration route, dredging of spring pond areas to increase brook trout spawning potential (however, dredging of the mainstem is not recommended), and addition of downed conifers, rootwads, and other forms of large woody debris throughout the system to compensate for wood removed since the late 1800s. Existing instream habitat improvement structures that seem to have been useful should be refurbished. Public acquisition of any part of the Cedar Island spring pond area to be again made accessible for wild brook trout spawning should be a high priority if that property becomes available; a substantial boost to the brook trout population would likely result given the apparent paucity of spawning areas for that species elsewhere throughout the upper river.

3. Continue the trend for increasingly restrictive angling regulations. Increasingly restrictive regulations have contributed to a brighter future for the salmonid fisheries, especially since over-exploitation was identified as one of their major threats. This trend should be maintained, and gear restrictions for sections of the upper river should be considered pending determination of the effects of the 1989 regulatory changes on the salmonid populations.

4. Further monitoring of the stream biota. The recent establishment of numerous exotic species serves to remind us that the Brule River is part of a larger ecosystem that will remain continually at risk from distant occurrences. Given the climate of uncertainty under which the system must be managed, there will be a need for periodic monitoring of the fish and aquatic insect communities to test for impacts of exotic animals on native species. Additionally, an abbreviated sampling schedule of the quantitative investigations into salmonid population dynamics initiated during the last decade should continue, as much as economically feasible, to ensure benefits to future fisheries management.

5. Continue the research focus. Many indications from the public including the admirable work of the Brule River Committee and the committee's strong support of the research efforts of the last decade suggest that status quo management of this river system is not acceptable. The public has a right to expect state-of-the-art management on a resource as valuable as the Brule River. Resource management policies have come under increased scrutiny from special interest groups and this trend will likely continue. Continuing research will be needed to satisfy the demand for sound management.

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Endnotes

[1] Coaster brook trout apparently exhibited an anadromous life history strategy similar to that of the anadromous brown trout. Little scientific information on coaster brook trout in Great Lakes tributaries is available because most populations were extirpated before scientific data were collected. Bullen (1988) describes a remnant population in a Lake Superior tributary.

[2] Upper river refers to the river reach from U.S. Highway 2 south (upstream) to the con-

fluence of the East and West forks. Lower river refers to the river reach from U. S. Highway 2 north (downstream) to Lake Superior. Upper or above always refers to an upstream direction; lower or below always refers to a downstream direction. Mainstem refers to the main thread of the Brule River proper without the tributaries.

[3] The lakes section is composed of four widespreads of the Brule River (Sucker, Big, Lucius, and Spring lakes) located just south of the river's midsection (Fig. 1).

[4] There is likely much less large woody debris in the Brule River (and other rivers and streams in northern Wisconsin) than there was historically for several reasons in addition to the removal efforts of early fisheries workers. Woody debris has been systematically removed from our rivers and streams for more than a century to maintain open channels for human navigation, and during the intensive logging era of the late 1800s removal efforts were intensified to maintain smooth channels for the downriver transport of logs. Additionally, the clear-cutting of our northern forests at that time (which included steamside areas) temporarily interrupted the continual natural process of dying streamside trees falling into waterways.

[5] The ledges section is the reach of river having maximum gradient where it crosses the Copper Range (Fig. 1). The river descends 80 ft in 2¼ miles at that point (Bean and Thompson 1944).

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Social behavior of adult jaguars (Panthera onca L.) *at the Milwaukee County Zoo*

Abstract *The purpose of this study was to describe and analyze social behavior between two captive jaguars* (Panthera onca *L.*)*, a male and a female, at the Milwaukee County Zoo. Some one hundred eighty-nine bouts were recorded and analyzed over four years. These bouts consisted of numerous acts, some of which appeared to be sex-specific or at least individual- specific. The bouts varied considerably in duration; the mean duration of the bouts initiated by the male was significantly longer than that for bouts initiated by the female. Two-act sequences for each animal revealed a large number of complex grooming and wrestling acts, with much switching back and forth. Apparent sex differences were revealed in the two-act sequences of complex grooming and clasping, clasping and lying on, and wrestling and lying on. As the study progressed, the male spent a significantly greater percentage of bout time in sexual behavior during the bouts.*

The jaguar (*Panthera onca* L.) is one of the least studied large cats in the world (Rabinowitz and Nottingham 1986). Until recently, the only published information available on the jaguar came from anecdotal reports of explorer-naturalists, hunters, and surveyors (Crawshaw and Quigley 1991). The recent scientific papers focus on various aspects of jaguar biology, such as home ranges, movements, and daily activity patterns (Crawshaw and Quigley 1991; Rabinowitz and Nottingham 1986; Schaller and Crawshaw 1980). Other published works emphasize various aspects of their predatory behavior (Emmons 1986; Mondolfi and Hoogesteijn 1986; Rabinowitz 1986b; Schaller and Vasconcelos 1978). Despite this, little is known regarding jaguar social interaction patterns (Mondolfi and Hoogesteijn 1986). The purpose of this paper is to provide an ethogram ("a set of comprehensive descriptions of the characteristic behavior patterns of species" [Brown 1975]), in this case limited to social behaviors. This paper describes social interactions between two captive jaguars (a male and a female) at the Milwaukee County Zoo over a four-year period. In addition to the description of individual acts, the duration of interactions was examined, the sequences of acts was analyzed, and variation over the study period was monitored.

Methods

The subjects of this study were both captive born (male: February 10, 1983; female: September 22, 1982) and had been housed together since September 15, 1983. The period of observations extended from October 22, 1985, to July 17, 1990. During this time the male was sexually unaltered while the female was maintained on Melangesterol (a progesterone derivative) implants until July 1990, when an ovariohysterectomy (spay) was performed. The study was terminated at that time.

Observations were made two to three times per week during the snow-free months of the year in Milwaukee (from May to early December) when the animals were released into the outside enclosure, an area 40 x 60 ft (12.2 x 18.3 m) (Fig. 1). Observations lasted from 30 to 60 min, depending on the level of activity. Social interactions were recorded by means of a video camera with a built-in timer and were analyzed later. The interactions consisted of bouts, "relatively stereotyped sequence[s] of behaviors that occur in a burst" (Lehner 1979). A bout extended from first contact (an obvious act of initiation of social interaction such as a fixed gaze) to termination (when one or both animals withdrew and did not reunite within 30 s). The initiator of the bout was the individual that approached the other (receiver) or initiated first contact.

The bouts were recorded, and the sequences of motor acts or patterns within the bouts were obtained by replaying the video tapes on slow speed. Accurate analysis of rapidly changing events was facilitated by the fact that the male is black and the female spotted. Two-act sequences (Latour 1981) were presented to contrast the behavior of the male to that of the female, both as initiator and as recipient. Changes in relative frequencies of some of the more common acts were examined for the study period.

Results and Discussion

An ethogram is the starting point in any ethological research (Lehner 1979). Although the behaviors of various cats have been documented (e.g. Schaller's [1972] work on the lion [*P. leo* L.] Wasser's [1976] thesis on tiger [*P. tigris* L.] play, and Leyhausen's [1956] and West's [1974] papers on the domestic cat [*Felis catus* L.]), there are no reports describing jaguar social behavior.

In order to construct the ethogram, several hundred contact bouts were recorded, one hundred eighty-nine of which were unobstructed enough for analysis. The bouts were described by the acts they contained.

Non-Contact Acts and No Activity

Non-Contact Acts:

• Fixed gaze (FG) – The animal initiated the bout with its head and neck held low and oriented toward the recipient animal. The animal rapidly shifted weight from one front leg to another.

Fig. 1. The female jaguar (right) and the male jaguar in their outdoor enclosure

• Stalking (St) – The initiator moved slowly with a fixed gaze toward the recipient. The body was tense and held in a lowered manner; the forequarters were usually held lower than the hindquarters.

• Rushing (Rus) – One animal ran toward the other, who did not flee.

• Chasing (Ch) – One animal ran toward the other, who did flee.

• Approaching (Ap) – One animal simply walked toward the other.

• Facing off (FO) – The initiator's head was oriented toward the other animal, who would or would not do likewise. The animals were in close proximity to each other, usually about a body length or less apart.

• Walk/run away (WA/RA) – The animal walked or ran away, usually ending the bout.

No Activity (NA):

This category was probably more artificial than the rest. It ranged from the relaxed mode of behavior seen when one animal remained motionless while being licked by the other, to a lack of discernible activity on the part of both animals. This category involves no reciprocity of actions whatsoever.

Contact Acts

Playing Behavior:

• Rubbing (Rub) – Rubbing often was the first actual physical contact between the two animals. One animal would rub the other using its head or body.

• Holding (Ho) – Holding was accomplished by throwing either one front leg over the neck or shoulder of the subject, or by placing both front legs around the other's neck. In some cases it appeared to restrain, while in others it was less forceful.

• Grabbing (Gr) – Grabbing was done by the rapid thrust of one of the front paws out and around the leg of a fleeing animal.

• Jumping on Back (JOB) – The animal placed its forequarters on the other's back. The front legs were usually straddled over the subject, and the hind legs may or may not have been on the ground.

• Pawing (Pa) – The subject was struck with the forepaw. The intensity of pawing varied greatly.

• Biting (Bi) – Biting covered a range in activity from a brief mouthing to a much more sustained biting and pulling.

• Wrestling (W) – Wrestling ranged from a close embrace with combinations of pawing, biting, and kicking with the hind legs, to a loose relationship with one animal lying on its back and the other animal standing over or near it. The animal lying on its back would often paw or reach with its front feet while treading with its hind legs; the mouth was held open and the teeth were exposed. The standing animal's mouth was also open while it bit and pawed at the lying animal. The belly-up and stand-up positions were sometimes interchanged and often mixed with close contact wrestling. The intensity of wrestling varied considerably.

Grooming behavior:

• Simple licking (SL) – In this situation one animal simply licked the other, from either a standing or lying position. The recipient of the simple licking did nothing (listed as NA). Both animals did this.

• Complex Grooming (CG) – In this complicated act, the female straddled the male who was belly side up, and she would lick him. This behavior was more protracted than simple grooming, and the animals were always in the straddle-belly up positions. This was maintained as long as she continued to lick him. This belly-up position differs from the NA behavior insofar as he actively participated in the sequence of events. When she stopped, he would start wrestling and either she would resume grooming and he would again relax, or she would wrestle with him.

Sexual behavior:

• Clasping (Cl) – The male hugged the female closely while both were lying on their sides. The male would pull the female against his chest and pull her down toward his stomach while treading with the hind feet.

• Lying on (LO) – With her head at or below the level of his stomach, the male rested his body on the female. While doing this, he would often move back and forth over the recumbent female, sometimes displaying a partial erection.

• Mounting (Mo) – The male straddled the female who was sitting or lying on her belly.

The results of this study demonstrate that within the conditions of captivity jaguars socially interact in bouts. The data support the idea that playing, grooming, and sexual behaviors often are found in the same bout. Bout duration varied considerably, with a range of 1 to 1204 s (Fig. 2). The majority (57%) of the bouts were less than 1 min long. These short bouts often consisted of one of the approach acts, followed by one of the contact acts such as biting or pawing, and usually ended with a walk-away or run-

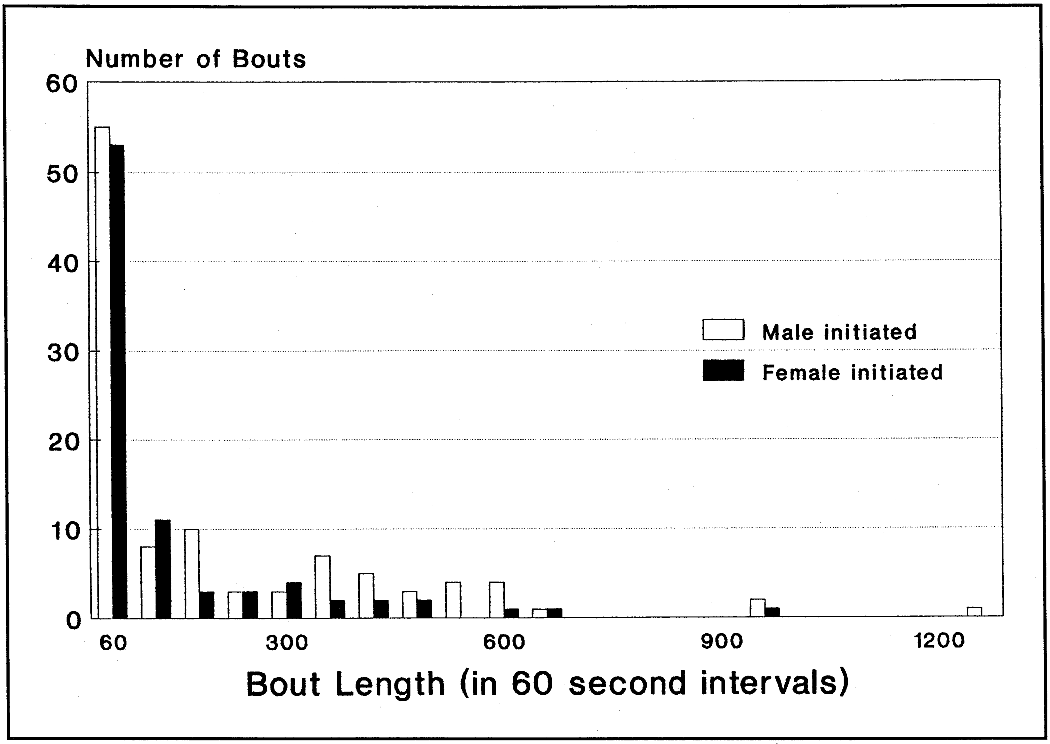

Fig. 2. Distribution of bouts by length

away. The longer bouts began and ended much as the shorter ones did, but contained a reciprocal switching of contact acts. The male initiated 106 bouts and the female initiated 83 bouts, with no significant difference between initiators (test concerning proportions, $z = \pm1.67$, $P > .05$). The mean duration of the bouts initiated by the male (174 s) was significantly longer than that for the bouts initiated by the female (99 s) (t-test, $t = 2.51$, $P < 0.01$).

Bouts were each analyzed as being composed of a series of two-act sequences of successive acts by the same animal. The integration of individual acts and the differences between the two animals is seen in these two-act sequences (Figs. 3–6). The area of each box in Figures 3–6 is proportional to the total number of acts, and the arrow width is proportional to the total number of transitions between the acts. For the sake of simplicity, only those transitions of ten or more were included.

Complex grooming and wrestling were the most common acts seen in both animals, both as initiator and as receiver. As the arrows suggest, these two acts often switch back and forth during a bout. It is of interest that prolonged wrestling, a common play act seen here, did not occur in wild adult lions (Schaller 1972).

While most of the acts were performed by both animals, there were a few that appeared to be individual-specific or sex-specific. Complex grooming varied between the animals, with the female always straddling the belly-up male. The male's position was maintained as long as she continued to lick

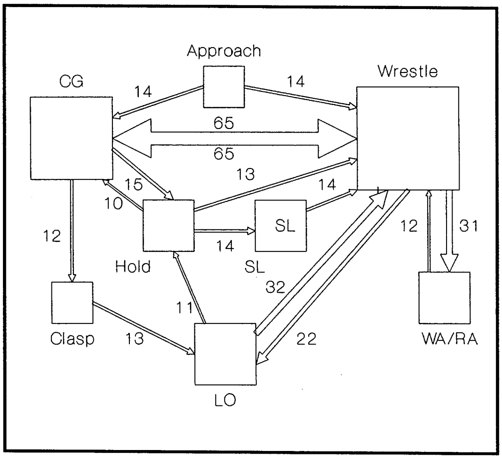

Fig. 3. Two-act sequences for male as initiator

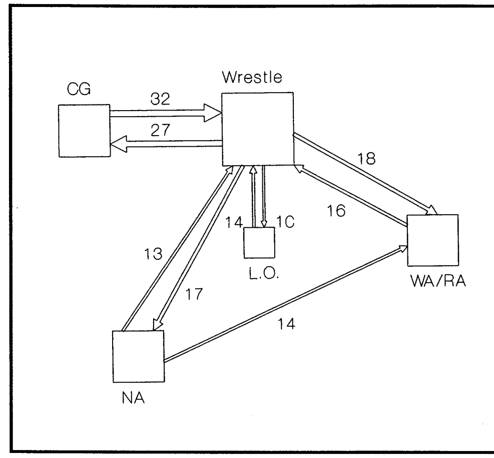

Fig. 4. Two-act sequences for male as receiver

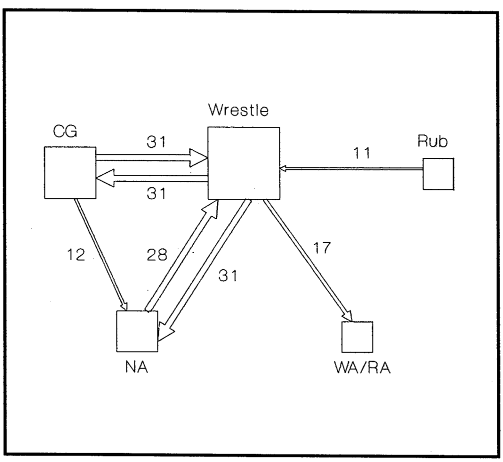

Fig. 5. Two-act sequences for female as initiator

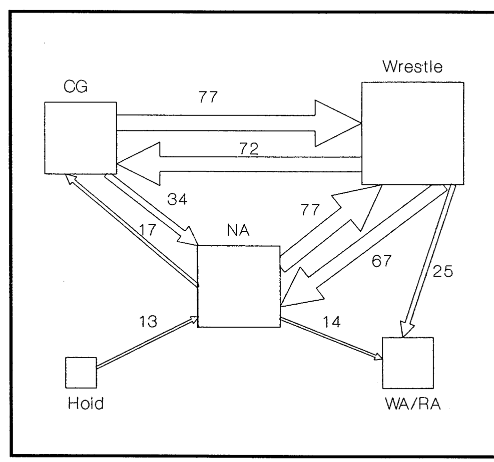

Fig. 6. Two-act sequences for female as receiver

him. If she stopped, he would start wrestling, and either she would resume the complex grooming and he would again relax or she would wrestle with him. A similar reaction was seen in the bite-lick-bite sequence in tigers (Wasser 1978) and in the use of social grooming as an interruption of playfight (Fagen 1981).

Only the male engaged in clasping, lying on, or mounting (all sexual) behaviors. As the study progressed, a shift was apparent (Fig. 7). There was a significant change in the proportion of time engaged in sexual behavior during the four years (the difference between proportions test was, for 1987–88, $z = -6.72$; for 1988–89, $z = -13.15$; and for 1989–90, $z = -6.82$, $P < 0.001$). His two-act sequences often included wrestle-lie on, lie on-wrestle, wrestle-clasp, and clasp-lie on; clasp appeared to be transitional between wrestling and lying on. When the male would either clasp or lie on the female,

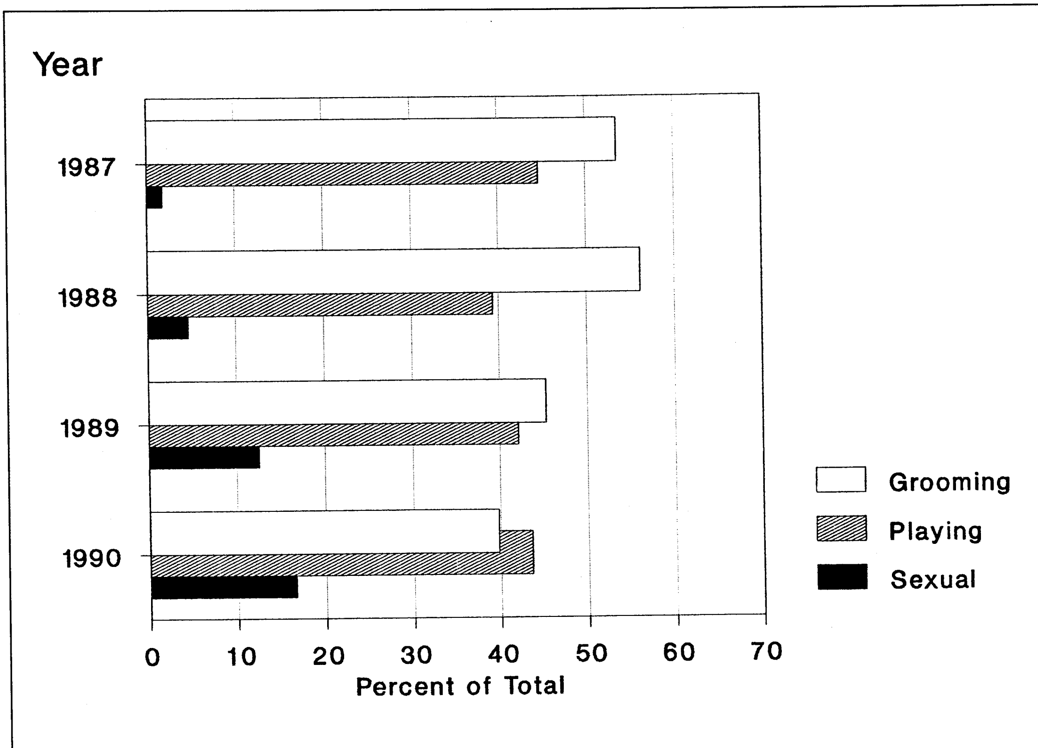

Fig. 7. Distribution of contact behaviors, 1987–1990

she would lie still (NA) or wrestle. Mounting was too infrequent to warrant placing in the two-act sequences; the female usually walked away from him as he attempted to do this. While Wasser's (1978) tiger bouts included contact behaviors such as paw, bite, wrestle, and lick, they lacked any sexual activity, possibly because his tigers included only one adult male and five of its offspring (one sub-adult and four cubs).

The progressive increase through the four years in the percentage of sexual behavior cannot be attributed to the development of sexual maturity. The animals were adults when the study started. He was 4.5 years and she was 5 years old, and they had produced a cub before the observations started. Rabinowitz (1986a) considered jaguars to be subadults at 2–3 years and mature adults at 4–10 years. Mondolfi and Hoogesteijn (1986) gave 2–2.5 years for sexual maturity in the female jaguar and 3–4 years for the male jaguar.

Unlike the complex grooming and the sexual behaviors, the acts that constitute play appeared not to show individual or sex differences. This is in agreement with Fagen's (1981) prediction that in carnivores, where both sexes display similar fighting skills, no differences should exist in play. In both animals the play demonstrated some accepted characteristics: exaggerated and repeated acts (Loizos 1966; Fagen 1981). Among the many functions attributed to play, expending excess energy (Bekoff 1976; Schaller 1972) and strengthening social bonds (Schaller 1972) were two that may have merit here. In confinement, male and female felids often live together in relative peace and may frequently play with each other, phenomena seldom recorded in the wild (Fagen 1981). In the wild, all felids, with the exception of the lion and the cheetah (*Acinonyx jubatus* Schreber), live solitary lives (Bekoff 1989). Hemmer (1978) suggested that carnivores are capable of a much greater plasticity in social behavior in zoos than they usually are in nature. He proposed that there are three factors that affect sociality in the pantherines: (1) environment, (2) relative brain size, and (3) temperament. He believed that the jaguar and the leopard (*P. pardus* L.) are capable of group living but, like the tiger, are forced by habitat conditions in the wild to forgo this.

Detailed longitudinal field observations of identified individual felids are still lacking (Bekoff 1989), and the evidence presented here is limited to only two captive jaguars; nevertheless, this study, which covers four years in the lives of two readily identified individuals, supports Ewer's (1973) contention that felids are not as asocial as commonly believed. The observations indicate that social behavior is organized into bouts of varying length and complexity and that the contact portion of the bout is dominated by play and complex grooming activity.

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Richard E. Koske and Leonard L. Tews

Vesicular-arbuscular mycorrhizal fungi of Wisconsin's sandy soils

Abstract *The root zones of beach grass,* Ammophila breviligulata, *of Wisconsin's Great Lake's dunes, and of other plants of sandy soils of the state were surveyed for the first time for vesicular-arbuscular mycorrhizal (VAM) fungi. The most frequently obtained were* Glomus etunicatum, Gigaspora rosea, Glomus geosporum, *and* Glomus macrocarpum. *Taxonomic characteristics of the obtained fungi are similar, in most cases, to those of VAM fungi found elsewhere.*

The soils of Wisconsin heretofore have been unexamined for vesicular-arbuscular mycorrhizal (VAM) fungi. Moreover, there have been only a few reports of VAM fungi being isolated from the lacustrine dunes of the Great Lakes region of North America (e.g., Koske et al. 1975; Koske 1985). Be that as it may, there have been numerous reports of VAM fungi from North America's maritime dune systems (e.g., for New England, Koske and Halverson 1981; Koske 1981; and for the Northwest, Gerdemann and Trappe 1974). It is of ecologic and taxonomic interest to know the VAM fungi of Wisconsin's soils, since they have potential in the improvement of crop production. Moreover, it is worthwhile to compare the VAM flora of the Great Lakes dunes to those of New England's dunes, especially since the higher plant flora, and therefore the ecology itself, is so similar.

Procedures

VAM fungi were collected from the root zones of plants at 53 sites at 21 different geographic locations (described with their sampling dates in Table 1). The sites included dunes of

Table 1. Collected species found in association with VAM fungi

Site	*Species Association*	*Date Collected*
1. Cornucopia (Bayfield Co.)	*Ammophila breviligulata* Fern. growing on Lake Superior dunes at Cornucopia's public beach	July 3, 1984
2. Rock Island (Door Co.)	*Agropyron dasystachum* (Hook) Scribn. growing on Lake Michigan dunes	July 22, 1984
3. Washington Island (Door Co.)	*A. breviligulata* growing on Lake Michigan dunes	July 22, 1984
4. Newport State Park (Door Co.)	*Calamovilfa longifolia* (Hook) Scribn. growing on Lake Michigan dunes	July 22, 1984
5. Bailey's Harbor (Door Co.)	*A. breviligulata* from Lake Michigan dunes at The Ridges beach (remnant arboreal forest)	July 21, 1984
6. Jacksonport (Door Co.)	*A. breviligulata* growing on Lake Michigan dunes at Jacksonport's public beach	July 21, 1984
7. Whitefish Dunes State Park (Door Co.)	*A. breviligulata* growing on Lake Michigan dunes	July 21, 1984
8. Kewaunee (Kewaunee Co.)	*A. breviligulata* growing on dunes at Kewaunee Pioneer Park	June 16, 1985
9. Two Rivers (Manitowoc Co.)	In the root zone of *A. breviligulata* growing on dunes at Two River's public beach	June 16, 1986
10. Kohler-Andrae (Sheboygan Co.)	*A. breviligulata* growing on Lake Michigan dunes at Kohler-Andrae State Park	July 21, 1984
11. Kohler-Andrae (Sheboygan Co.)	*A. breviligulata, Lathyrus maritimus* (L.) Bigelow, *C. longifolia*, and *Rosa* sp. growing on Lake Michigan dunes at Kohler-Andrae State Park	October 9, 1983
12. Harrington Beach (Ozaukee Co.)	*L. maritimus* and *A. breviligulata* growing on Lake Michigan dunes at Harrington Beach State Park	July 11, 1984
13. Sauk City (Columbia Co.)	In the root zone of *A. breviligulata* growing on a bank of the Wisconsin River in Sauk City	June 21, 1985
14. Lake Wisconsin (Columbia Co.)	Sedges and *Lythrum salicaria* L. growing on a sandbar in Lake Wisconsin	June 21, 1985
15. Plainfield (Waushara Co.)	Associated with the roots of *Z. mays* L. near an irrigated field near Plainfield	June 27, 1985
16. New Hope (Waupaca Co.)	From an unirrigated oat field near New Hope	June 27, 1985

Site	Species Association	Date Collected
17. New Hope (Waupaca Co.)	From an unirrigated field of *Z. mays* near New Hope	June 27, 1986
18. Red Granite (Waushara Co.)	*Poa pratensis* L. from a granite quarry near Red Granite	June 27, 1985
19. DeWitt Road (Sheboygan Co.)	*A. breviligulata* on Lake Michigan dunes at the end of DeWitt Road	July 11,1984
20. Plainfield (Waushara Co.)	From an irrigated and an unirrigated field of *Z. mays* near Plainfield	June 27, 1985
21. Columbia Co.	From an irrigated field of soybeans	July 9, 1985

Lake Michigan and Lake Superior, sandbars and banks of the Wisconsin River, and irrigated and unirrigated sandy soils of central Wisconsin. Sand-root samples were placed in plastic bags and stored at about 6°C until processed. Field notes regarding position, date, and vegetational cover were recorded.

Spores of the VAM fungi were separated from the soil by a technique of flotation and filtration (Koske and Halvorson 1981). Approximately 35 g of sand were added to about 500 ml of tap water in a 1 liter beaker and agitated vigorously. The suspension was filtered immediately, before settling, through a .5 mm soil sieve with the spores being collected on a No. 4 Whatman filter paper placed in a Buchner funnel with vacuum pressure. The filter paper was removed from the funnel and placed under a dissecting microscope where spores of the fungi were isolated to a drop of water on a glass slide with the aid of a fine forceps. A cover slip was placed atop the spores, and with gentle pressure, the spores were burst for better examination of spore wall structure. Spores were sometimes stained with Melzer's Reagent for diagnostic purposes. If a permanent slide was desired, spores were placed in a drop of polyvinyl alcohol solution and sealed with clear fingernail polish.

Results

Fifteen species of VAM fungi were collected from the sandy soils of Wisconsin (Table 2). All species are new records for Wisconsin. The fungus most frequently isolated from sand dunes was *Glomus etunicatum.* Other commonly obtained fungi are *Gigaspora rosea*, *Gl. geosporum* and *Gl. macrocarpum*.

The VAM fungi of Wisconsin's dunes were compared to those of other soils using a coefficient of similarity, *C* (Bray and Curtis 1957) (Table 3). The equation is: $C = 2w/a + b$ where w = the number of species common to both floras, a = the number of species of one flora, and b = the number of species of the other flora. The VAM fungi of Wisconsin's dunes are most similar to those of Wisconsin's non-dune soils, and somewhat more similar to those of Iowa than they are to those of the maritime dunes of Rhode Island or the prairie soils of Illinois.

One of the obvious differences between the VAM floras of Iowa, Wisconsin, and Rhode Island is that *Gigaspora-Scutellospora*

Table 2. VAM fungi collected from Wisconsin's Great Lake dunes and other sandy soils

Species	*Sites from which species were isolated**
Acaulospora scrobiculata Trappe	9,13
A. spinosa Walker & Trappe	11,14,16
Gigaspora rosea Schenck & Smith	9,10,11
Gi. gigantea (Nicol. & Gerd.) Gerd. & Trappe	9,13,14
Glomus aggregatum Schenck & Smith	4,11
Gl. caledonicum (Nicol. & Gerd.) Gerd. & Trappe	5
Gl. etunicatum Becker & Gerd.	3, 4, 5, 6, 7, 9,11,12,14,17,19
Gl. geosporum (Nicol. & Gerd.) Walker	9,11,18, 20, 21
Gl. macrocarpum Tul. & Tul.	11,18
Gl. microaggregatum Koske, Gemma & Olexia	1, 8
Gl. mosseae (Nicol. & Gerd.)	15, 20, 21
Gl. lamellosum Dalpe, Koske & Tews	5,10,11
Glomus sp. B.	10,11
Scutellospora calospora (Nicol. & Gerd.) Walker & Sanders	1,11
S. dipapillosa (Walker & Koske) Walker & Sanders.	15

*Numbers indicate the site from Table 1 from which the fungi were collected.

complex seems to be a more important component of Rhode Island's flora. (These genera are combined on Table 4 since the separation of *Scutellospora* from *Gigaspora* occurred after most of these studies were reported). In the Rhode Island dunes, 44% of the collected species are of the genera *Gigaspora-Scutellospora* whereas in the dunes of Iowa and Wisconsin this figure is much lower (Table 3). The relative importance of *Acaulospora* also differs. In the Rhode island dunes, only one species, *A. scrobiculatum*, was obtained. In the midwestern soils of Iowa and Wisconsin, 20 to 25% of the species belonged to the genus *Acaulospora*. In addition, the genus *Glomus* appears to be more important in the midwestern soils than it is in Rhode Island dunes.

Discussion

For the most part, VAM fungi collected from Wisconsin resemble those collected elsewhere. Nevertheless, there are some exceptions. The azygospores of *Acaulospora spinosa* are small, but fall within the range of Walker and Trappe's (1981) description. The spores and suspensors of *Scutellospora calospora* are smaller than those reported by Gerdemann and Trappe (1974), but probably this is not enough of a difference to warrant a new species. The walls of *Gl. aggregatum* did not exhibit the greenish tint previously reported as sometimes present (Koske 1985). The chlamydospores of *Gl. caldeonicum* fall below the range of those of Gerdemann and Trappe (1974). The walls are thicker than

Table 3. The VAM fungi of Wisconsin's Great Lakes Dunes compared to those of other soils using a coefficient of similarity, *C*

	C
Wisconsin non-sandy soils	.84
Iowa soils (Walker et al. 1982)	.44
Rhode Island maritime dunes (Tews and Koske 1986)	.30
Illinois prairie soil (Anderson and Liberta 1989)	.25

Coefficient of similarity, *C* is calculated by using the fomula $C = 2W/a + b$, where w is the number of species common to both populations, a is the number of species in one population, and b is the the number of species in the other population.

Table 4. The relative importance of the VAM Genera collected from four different areas in terms of the percent of species of each genus

Site	*% Gig-Scut*	*% Acaulopora*	*% Glomus*	*% Sclero*
Wisconsin dune	23	21	57	0
Wisconsin non-dune	25	25	50	0
Rhode Island dune	44	11	44	0
Iowa soils	26	20	53	0
Illinois soils	33	0	50	17

those reported earlier, and they are sometimes tinged with a pale pink, which may be the result of a bacterial invasion carrying the pigment. Again, these differences are not important enough to warrant naming a new species.

The chlamydospores "*Gl. tortuosum*" are about twice the size of these of Schenck and Smith (1982). The spore wall is about three times thicker. They reported a single laminate wall; four were observed here. The width of the attachment is three times that reported by Schenck and Smith.

The higher plant flora of the lacustrine dunes of the Great Lakes are similar to those of the maritime dunes of New England, but their VAM fungal flora vary greatly. In a study of Moonstone Beach (Tews and Koske 1986), a barrier dune in Rhode Island, only two of the nine species isolated, *S. calospora* and *Gl. aggregatum*, were similar to those of the present study. Three species in the Moonstone study had a frequency of over 50%: *A. scrobiculata*, *Gi. gigantea*, and *S. persica*. None of these appears in the present study. The most commonly isolated fungi in the present study are *Gl. etunicatum*, *Gl. macrocarpum*, and *Gl. aggregatum;* only the latter was isolated from Moonstone Beach.

The fungal flora of Wisconsin's Great Lakes dunes are at least as similar to that of the disturbed stream and river bank soils of central Iowa (Walker et al. 1982) as they are to the dunes of Rhode Island. There were three species in common with the Iowa study: *A. spinosa*, *S. calospora*, and *Gl. geosporum*. Nevertheless, the higher plant flora of the Iowa study (*Fraxinus americana* L., *Bromus inermis* Leyss, and *Setaria* spp.) differed greatly from that of the Great Lakes dunes. Furthermore, at one site the soils were not sandy but were composed of silt-loam.

If the flora of Wisconsin sandy soils are compared to that of a sandy prairie of Illinois (Anderson and Liberta 1989), we find that there are three species in common: *Gl. geosporum*, *Gl. fasciculatum*, and *Gi. gigantea*. This prairie soil was dominated by little blue-stem grass (*Schizachyrium scoparium* [Michx.] Nash).

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David J. Post

The plant communities of Nine-Mile Island – past and present

Abstract *Nine-Mile Island, in the Chippewa River, west-central Wisconsin, is currently under consideration for purchase as a natural area by the Wisconsin Department of Natural Resources. Logging and agricultural use would be limited while occasional controlled burning would be utilized in certain areas to maintain the prairies. Hunting and other public uses of the land for enjoyment would still be permitted. A description of the vegetation of Nine-Mile Island is presented. Land Office survey records from 1848–49 indicate at that time the island was about 35% floodplain forest, 25% oak openings, and 40% mesic forest. Settlement was limited to a single small farm. 1990 quadrat sample data were used to trace changes that occurred since that time. Little change was found to have occurred in the extent and composition of the forests, and the overall vegetation pattern now present appears to be similar to that found on the island in the 1800s. Size class distribution suggests little change in the composition of vegetation for the foreseeable future.*

Nine-Mile Island of the Chippewa River in west-central Wisconsin provided an opportunity to investigate the interactions between the vegetation and environmental factors in a relatively natural and undisturbed setting. Although human activities have exerted and continue to exert some influence on parts of the island, much of the original vegetation consisting of oak openings, oak forest, floodplain forest, and prairie is present at this time.

In 1991, the Wisconsin Department of Natural Resources (WDNR) acquired a 23.5 ha (63 acre) tract on the island, which is to be designated a natural area. This area is to be preserved intact as an example of lowland forest habitat. In addition, the WDNR has proposed the purchase of about 2145.75 ha (5300 acres), including the remainder of the island and some of the adjacent floodplain. This natural area will preserve the plant communities as well as bird and reptile species that are considered rare in Wisconsin.

In the establishment of a natural area it is important to determine "baseline" conditions and to integrate current data in describing the extent, distribution, and condition of existing vegetation types (Noss 1989). The purpose of this study was to describe the plant communities of the island and to identify environmental factors responsible for their presence. The original survey records of 1848–49 were used to reconstruct the vegetation of that era. The present vegetation was sampled using quadrats. Standard phytosociological analytical techniques were used to compare present community types with those of the past and to draw inferences about future compositional changes.

Study Site

Nine-Mile Island is located in the Chippewa River in southern Dunn and northern Pepin counties, Wisconsin. The island is located in sections 35 and 36 of Township 26 N and Range 13 W in Dunn County and sections 1, 2, and 3 of Township 25 N, Range 13 W in Pepin County (Fig. 1). It is about 56.5 km (35 mi) upstream from the Mississippi River, approximately 6.5 km (4 mi) north of the City of Durand, Wisconsin. The island is about 4.3 km (3 mi) long and 4.0 km ($2^1/_2$ mi) at the widest place, with a total area of about 1012 ha (2500 acres). The topography is basically flat with elevations ranging from 1.2 to 3 m (4 to 10 ft) above the normal level of the river. The channel is characterized by eroding banks of sand and gravel. The island is situated about 1.6 km (1 mi) below the confluence of the Chippewa and Red Cedar rivers and was formed by the presence of a back channel commonly referred to as Nine-Mile Slough. The back channel carries less water than the main channel and may be nearly dry when the river level is low, leaving much of the sand and gravel bed exposed. Changes have taken place in the river channel surrounding the island since about 1965. The meander on the southwestern part of the island was cut off, decreasing the size of the main island (Fig. 1). Also, the meander at the northeastern corner of the island was cut off at about the same time, causing another change in the configuration of the island. Figures depicting aspects of the island's vegetation prior to the changes in the river channel include the areas formerly considered a part of Nine-Mile Island.

Loose, river-deposited sand and gravel called "riverwash" occurs along the banks and shorelines (Fig. 1). The vegetation is sparse because the water level changes frequently and often floods the shoreline. At higher elevations the island is mostly sandy alluvial land with an isolated area of loamy alluvial land. The soils are nearly level sandy loams to silt loams and in places are nearly level and poorly drained with a silty clay-loam subsoil (USDA 1964, 1975). Frequent flooding occurs on the western one-third of the island where the average elevation is about 1.2 m (4 ft) above the normal level of the river. The normal level of the river was determined as the line of demarcation where terrestrial vegetation began (Peterson and Gamble 1968). Swamp hardwood vegetation and low land (below 4 ft above the normal level of the river) are prevalent on the western one-third of the island. The remainder of the island has an average eleva-

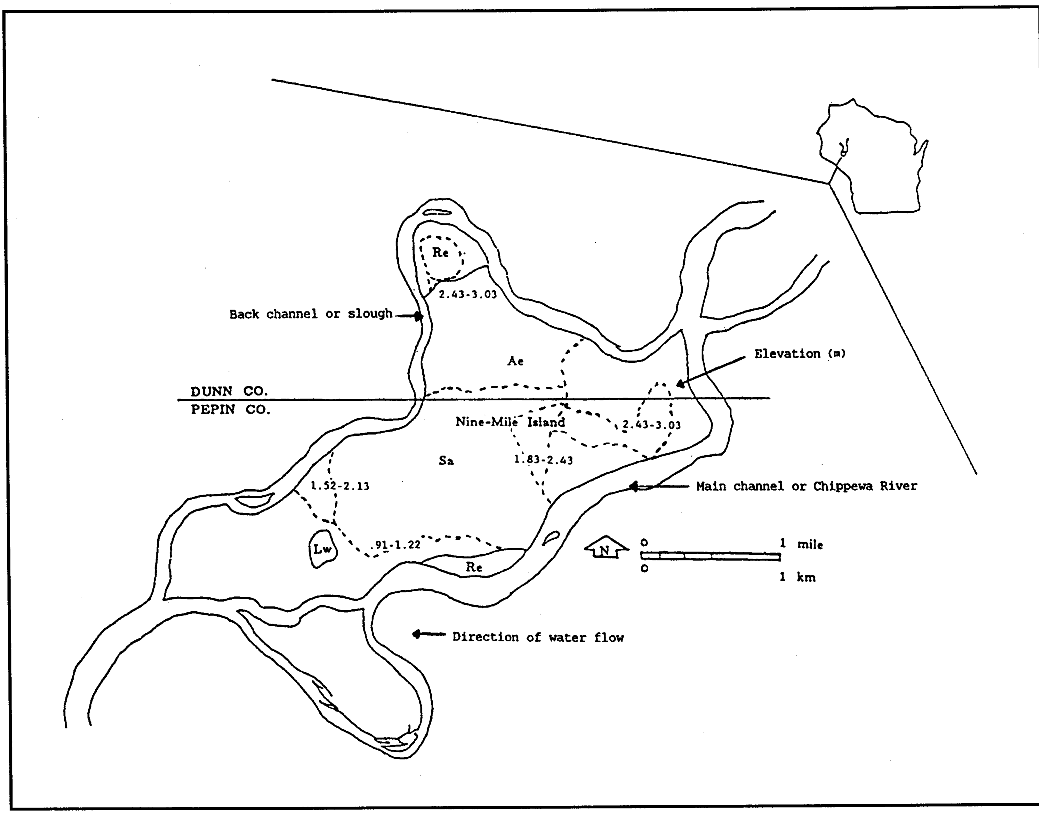

Fig. 1. Nine-Mile Island in its geographic setting on the Chippewa River, west-central Wisconsin. Soil types: Ae, alluvial land, sandy; Lw, loamy alluvial land, wet; Sa, sandy alluvial land; Re, riverwash. The dashed lines show elevation contours.

tion of about 1.8 to 3 m (6 to 10 ft) above the normal level of the river. Oak forests, scattered oak openings interspersed with remnants of prairie vegetation, and some mesic forest vegetation occur on these soils.

Flood frequency data for this region of the Chippewa River was obtained from an analysis that used a United States Geological Survey (USGS) method (USDA 1975). The mean annual flood is defined by the USGS as a flood having a recurrence interval of 2.33 years and occurring at an elevation of .9 m on this island. An elevation of 1.2 m can be expected to flood every five years; at 2.1 m, a flood can be expected every ten years. The entire island may be inundated once in about every 60 to 80 years. About 60% of the floods occur during the months of March and April (Barnes 1989).

History of Settlement

The original land survey of Nine-Mile Island and the surrounding area was conducted in 1848–49 prior to settlement. The surveyor described the island as level with second-rate sandy soils. The timber was described as black, white, bur, or red oak on the level and as maple, ash, elm, birch, aspen, and lind in the bottoms. Much of the vegetation was described as either timber, scattered timber, or simply as "bottoms."

The first settlers came to the island during or soon after the original survey was completed. During the late 1840s and as late as the 1850s there was a small wood-cutting operation located on the central part of the island. It provided fuel for the steamboats that periodically traveled on the Chippewa River between the Mississippi River and Eau Claire. Although there is no record of extensive use of the land for crops, hay and grasses were raised for forage, especially during the depression years (1930s) when farmers used all available land. The hay was often hauled across the ice during the winter. Also, cattle grazed on the island in a fenced pasture that encompassed at least 202 ha (500 acres) during the depression and in the years following. Remnants of the old fence as well as old mowing machinery are still present. There are accounts of an old ferry measuring about 4 x 10 m, connected to the island by ropes and cables, that was in service as late as the 1940s. This ferry was used to transport a team and wagon to the island to haul hay or to transport livestock. The only dwelling presently on the island is an old hunting cabin. On the same site are the remnants of an old barn foundation purported to date back to the 1850s as part of a small farmstead. This small farm was apparently occupied until the 1940s and was used to raise crops (Hubbard 1991). Finally, sportsmen use the island today to hunt an evidently ample deer population and other small game.

Original Vegetation

Data from microfilm copies of the original field notebooks were used to determine the approximate distribution and composition of plant communities present at the time of the original survey. Corner points were established at .8 km (.5 mi) intervals where east-west and north-south transects intersected (corners). A post was driven into the ground at each corner, and the distance and bearing to the four nearest trees was recorded along with their common names and diameters. If no trees were nearby, the surveyors constructed a mound of earth as a corner reference and so recorded it (Barnes 1989). A chain was used to measure the distance between section corners; about 80 chains is equivalent to 1.7 km (1 mi). The distances to the trees nearest the corner point were recorded in links (0.66 ft in a link).

Areas in which the trees were calculated to be more than 15 m apart were mapped as oak openings (<65 m) or prairie (>65 m) (Curtis 1959), while the remaining areas were mapped as either bottomland hardwoods or mesic hardwood forest (Fig. 2). Survey data used were from twenty corners that lie on Nine-Mile Island.

Eighteen of the twenty corner points were ascertained by the original surveyors to have trees less than 15 m (45 ft) apart, indicating that the island was about 93% forested in 1848. Three basic community types were present on the island as interpreted from the surveyors records: floodplain forest, mesic hardwood forest, and oak openings within which some small prairie occurred.

Floodplain forest comprised what was then about 33% of the entire island. Silver maple (*Acer saccharinum*), basswood (*Tilia americana*), and green ash (*Fraxinus pennsylvanica*) were the most common species, each occurring in 50% of the corner points. Also abundant in the floodplain forest were American elm (*Ulmus americana*) and black willow (*Salix nigra*) (Table 1). Butternut (*Juglans cinerea*) was also recorded in parts of the floodplain forest.

Oak openings occupied about 20% of the island at the time of the 1848–49 survey. (This includes land area that is no longer

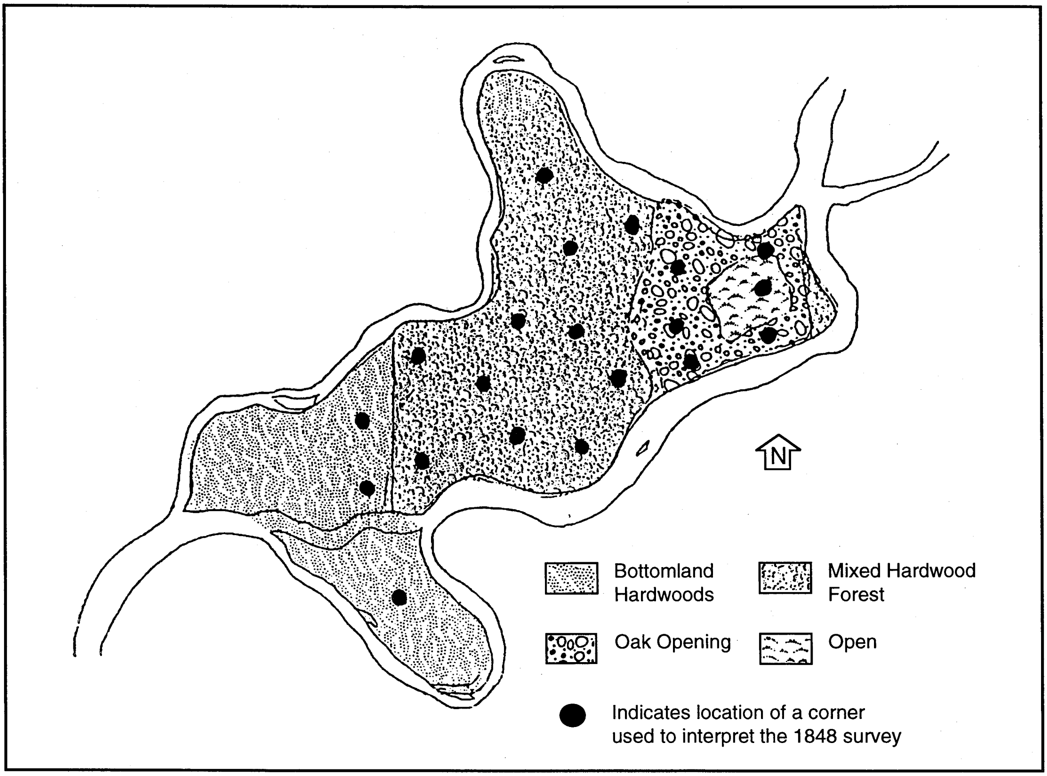

Fig. 2. The vegetation of Nine-Mile Island in 1848 as interpreted from the original survey records

part of the island proper.) "Black Oak," as listed in the survey records, was the most common species occurring in the oak opening community, being witnessed at 60% of the corner points. This may have been red oak (*Quercus borealis*) or Hill's oak (*Quercus ellipsoidalis*). White Oak (most likely *Quercus alba*) was also common here, occurring at 40% of the corner points. Other species present in the oak openings were American elm, hackberry (*Celtis occidentalis*), *Populus* sp., and river birch (*Betula nigra*) (Table 2). At one point along a line in this area of the island (between sections one and two in Pepin County) the surveyor recorded "entering prairie" but did not list prairie plant species. It may be possible to make an inference about the species that occurred in this area from Buss's (1956) study on the nearby Meridean prairie. He found that the most abundant plants occurring on undisturbed sites were big bluestem (*Andropogon gerardi*), spiderwort (*Tradescantia ohiensis*), and flowering spurge (*Euphorbia corollata*). Little bluestem (*Andropogon scoparius*), indian grass (*Sorghastrum nutans*), and purple prairie clover (*Petalostemum purpureum*) are species that Buss listed as being scattered.

A "mesic hardwood" forest, as inferred from the survey records, comprised about 45–50% of what remains the main part of the island. Here, the number of individuals of each species was more equal, although

Table 1. Frequency (%F), average diameter ($\bar{x}$dbh), and relative density (%RD)* of trees of the Floodplain Forest at the time of the original land survey (1848–1849) (5 corners, 12 trees)

Species	*%F*	*$\bar{x}$dbh (cm)*	*%RD*
Juglans cinerea	25	22.5	16
Acer saccharinum	50	25	33
Salix nigra	25	22.5	8
Tilia americana	50	25	10
Ulmus americana	25	45	12
Fraxinus pennsylvanica	50	22.5	20

*Relative Density (%RD) = % of total of all trees.

Table 2. Frequency (%F), average diameter ($\bar{x}$dbh), and relative density (%RD) of trees of the Oak Openings at the time of the original land survey (1848–1849) (6 corners, 11 trees)

Species	*%F*	*$\bar{x}$dbh (cm)*	*%RD*
Betula nigra	20	30	12.2
Populus sp.	20	27.5	12.2
Celtis occidentalis	20	30	8.3
Ulmus americana	40	32.5	18.2
Quercus alba	40	30	18
Quercus borealis	60	35	31.1

Table 3. Frequency (%F), average diameter ($\bar{x}$dbh), and relative density (%RD) of trees of the Mesic Hardwood Forest at the time of the original land survey (1848–1849) (9 corners, 12 trees)

Species	*%F*	*$\bar{x}$dbh (cm)*	*%RD*
Tilia americana	44.4	25	33
Acer saccharinum	33.3	45	16.6
Fraxinus pennsylvanica	11.1	22.5	8.3
Quercus macrocarpa	11.1	30	8.3
Ulmus americana	33.3	25	16.6
Quercus alba	11.1	22.5	8.3
Celtis occidentalis	22.2	27.5	8.3

basswood, typically listed as "lind," was the most abundant at 44.4% of the corner points. Other species that occurred frequently in the mesic hardwood forest were American elm at 33.3% of the corner points, maple (presumably silver maple) at 33.3% of the corners, and hackberry at 22% of the corners. In addition, some green ash, white oak, and bur oak (*Quercus macrocarpa*) were witnessed (Table 3).

The land throughout the island was described in the survey records as "surface level" with "second rate" soils. The vegetation pattern coincided with the present description in most respects except that there seemed to be less open land around the oak openings in 1848.

Present Vegetation

The vegetation was sampled during the autumn of 1990 using 1/100 ha (1/40 acre) circular quadrats to sample trees and 1/40 ha (1/1/00 acre) circular quadrats to sample herbaceous vegetation. One hundred seventy (1/100 ha) quadrats were placed along north-south transects established by a compass bearing at .32 km (.2 mi) intervals along the entire width of the island. Adjacent transects were spaced .32 km apart, so that the entire island was divided into a nearly regular grid pattern of quadrats. Tree diameters greater than 10 cm (4 in) at diameter breast height (dbh) were recorded using a diametric caliper, and sapling species were recorded as present or absent. Herbaceous species were also recorded as present or absent within the quadrats. Soil samples were collected at every tenth quadrat beginning with the fifth and continuing throughout the entire island. A consistent practice of collecting a sample of the top six inches of soil, after removing the leaves and other duff, was followed. The soil samples were analyzed for percentages of water-retaining capacity, sand, and organic matter. Elevation above the normal water level was estimated using a level and stadia rod.

Simpson's Diversity Index was used to calculate the degree of species diversity within each community. This index assigns a value between zero and one to a community; the closer the number is to one, the higher the diversity. A definition of biological diversity is "the variety and variability among living organisms and the ecological complexes in which they occur" (Noss 1989).

A two-dimensional polar ordination was performed using the importance values of the tree species to determine the difference in composition between the communities. The degree of compositional dissimilarity between each of the community pairs was determined using the 1 - (2w/a + b) index. Beal's (1960) geometric method was used to position the five communities in the plane defined by the first two axes.

A histogram was constructed for the major species in each community type to reveal their distribution of size classes. Trees were divided into size classes ranging from 10 cm (4 in) dbh to 30 cm (12 in) dbh.

A relative peak value method was used to infer possible successional changes in the mesic forest and floodplain forest. Succession may be defined as the replacement of some species by others through time. The end result of succession is a community in which the member species perpetuate themselves through reproduction, are in a dynamic balance with one another, and are in equilibrium with the prevailing environmental conditions (Buckholz and Pickering 1978). This technique plots the relative number of stems of all important species in a community against relative size classes. Using relative numbers removes the effect of numerous species having higher peaks. Using relative size classes (i.e., each size class is expressed as a percentage of the largest size class for the species) reduces the risk of misinterpretation because different species attain different maximum heights. The resultant line graphs show the peak number of a given species in each size class. The position of a peak number for a species relative to other species allows inferences to be made about possible successional trends in a stand. Young species will peak on the left side of the graph while older species will peak on the right side of the graph. A species with a peak value on the right side of the graph in a large size class is likely to be eventually replaced by a species with a peak value closer to the left side of the graph in a smaller size class.

Community Descriptions

Five community types were identified on the island: two oak openings, an oak forest, a mesic forest, and a floodplain forest (Fig. 3). Hill's oak and red cedar (*Juniperus virginiana*) were the most abundant trees of the seven species in Oak Opening I, which occurs at an average elevation of about 2.7 m (8 ft) above the normal level of the river (Table 4). This community occurs on sandy soil on the eastern end of the island and is mostly inland. White oak was also prevalent in this community, and basswood and green ash were the most common associates of the oak species. This oak opening had a density of 83.5 trees/ha, a compositional index of 397, and a Simpson's Diversity Index of .827. Silver maple and American elm trees and saplings were common, but were restricted to the low areas closer to the river. Green ash and basswood saplings were common throughout the area. In Oak Opening I, white oak was present primarily in the 25 to 30 cm (12 to 13 in) size range (Fig. 4). There were no small individuals and few saplings of white oak; most of the saplings and small trees were basswood and green ash, suggesting a change in future dominance and possibly a change from oak opening to forest. Fire was responsible for maintaining the oak openings in Wisconsin (Curtis 1959) and may be necessary to maintain this community type on Nine-Mile Island.

Table 4. Frequency (%F), mean diameter ($\bar{x}$dbh), relative density (%RD), and importance values (IV)* of trees in Oak Opening I (26 quadrats, 22 trees)

Species	*%F*	*$\bar{x}$dbh (cm)*	*%Rd*	*IV**	*Sampling Frequency (%)*
Juniperus virginiana	19.2	23.8	9.1	12.5	25
Quercus ellipsoidalis	15.4	62.5	4.6	15.2	35
Tilia americana	15.4	14.4	36.4	21.7	65
Quercus alba	11.5	36.7	13.6	17.2	40
Fraxinus pennsylvanica	11.5	28.8	18.2	18.3	65
Acer saccharinum	7.7	21.3	9.1	7.3	45
Ulmus americana	7.6	17.5	9.1	7.3	30

*Importance value (IV) is the number assigned to a tree species in a stand relative to other trees in that stand. It is an average of the relative density (how many trees are present), the relative dominance (size of the trees present), and the relative frequency (how often a tree occurs).

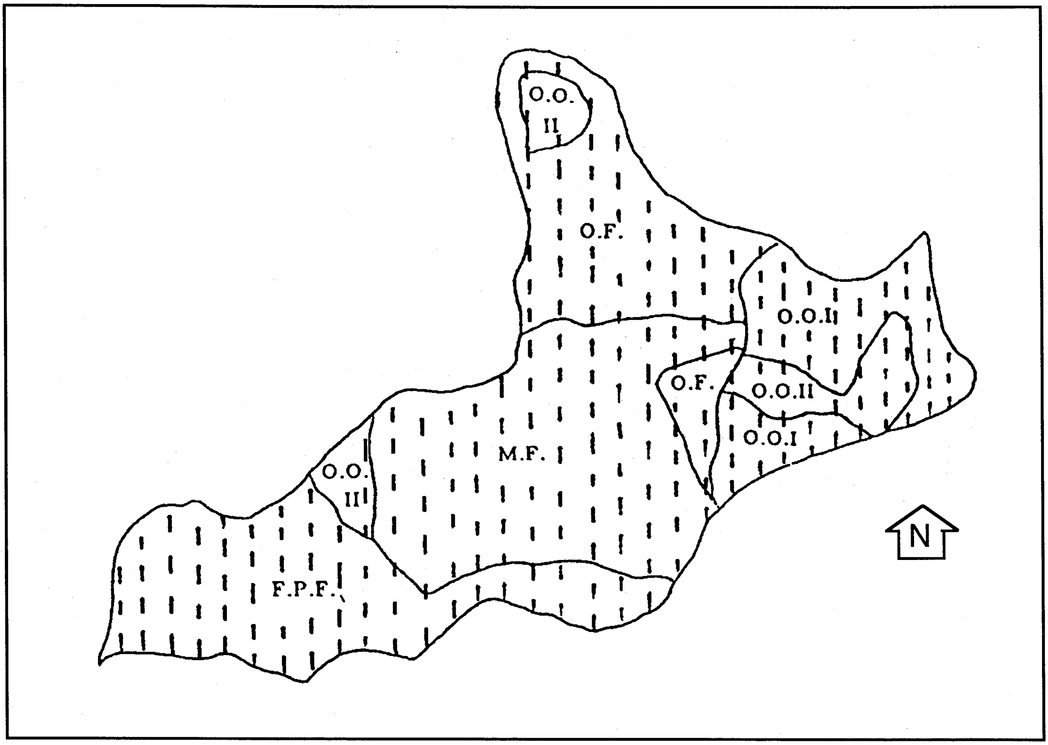

Fig. 3. The present vegetation of Nine-Mile Island as interpreted from sampling with quadrats and aerial photographs (Oak Opening I, O.O.I.; Oak Opening II, O.O.II.; Oak Forest, O.F.; Mesic Forest, M.F.; Floodplain Forest, F.P.F.). The dashed lines indicate north-south transects along which 1/40 acre circular quadrats were established at .32 km (.2 mi) intervals.

Shrubs present included prickly ash (*Zanthoxylum americanum*), prickly gooseberry (*Ribes Cynosbati*), and grey dogwood (*Cornus racemosa*), while staghorn sumac (*Rhus typhina*) was abundant in the open areas. Both big bluestem and little bluestem dominated in the oak openings along with abundant prairie smoke (*Geum riflorum*) and individuals of several species of goldenrod (*Solidago* spp).

Red oak, swamp white oak (*Quercus bicolor*), Hill's oak, and American elm were the most abundant of the eight species of trees in Oak Opening II (Table 5). This community is also located on the eastern end of the island and occurs at an average elevation of 2.4 m (8 ft) above the normal level of the river on sandy and poorly drained soils. White oak was also abundant in this community, and hackberry and green ash were common associates of the oak species. This community had an estimated density of 180 trees/ha, a compositional index of 506, and a Simpson's Diversity Index of .895. Green ash and hackberry saplings were relatively common as were pin oak (*Quercus ellipsoidalis*) and white oak saplings. The comparative size class distribution indicates a stable population of the dominant species with an abundance of red and white oak saplings as well as older, mature trees (Fig. 5). Prickly ash, grey dogwood, and staghorn

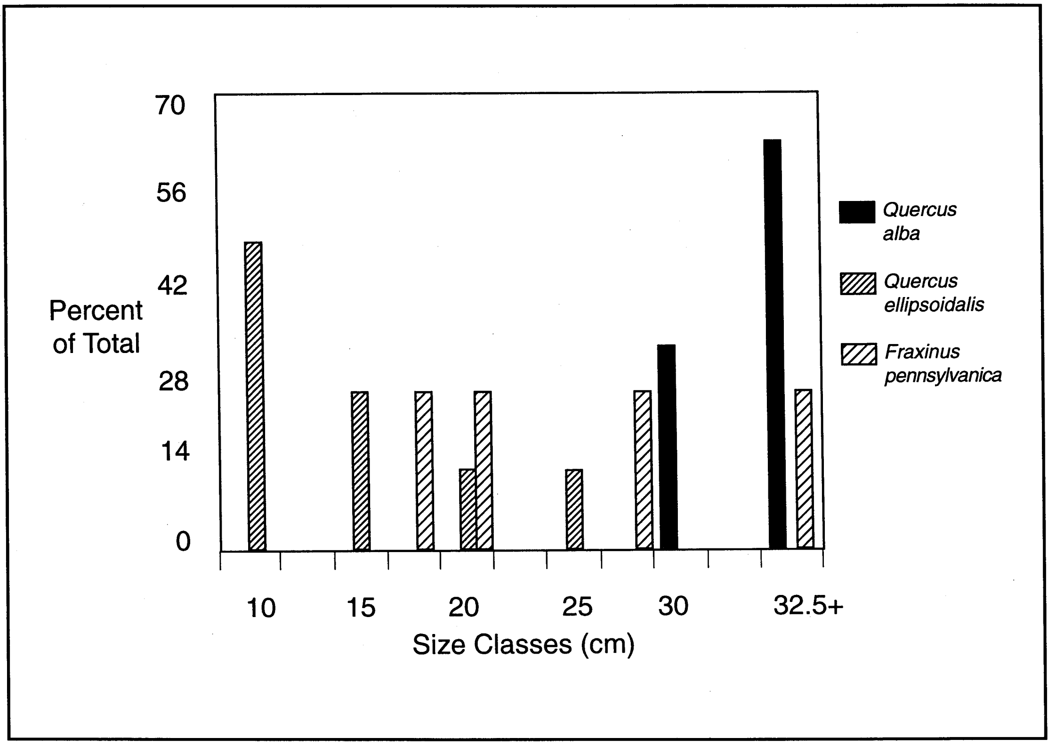

Fig. 4. Size class distribution of three important tree species in Oak Opening I

sumac shrubs were abundant in the open areas. Big bluestem, little bluestem, and rye grass (*Elymus canadensis*) were prevalent in this community along with abundant individuals of goldenrod. The two oak openings were distinguished by dominant oak species. Pin oak was dominant in the first oak opening while red oak and swamp white oak were dominant in Oak Opening II.

White oak was the largest and most abundant of the fourteen species of trees in the oak forest (Table 6). This community occurs toward the east-central part of the island at an average elevation of about 2.4 m (7.9 ft) above the normal level of the river, somewhat lower than the elevation of the oak openings. Red oak was also abundant, and to a lesser extent bur oak and Hill's oak were also present.

Yellowbud hickory (*Carya cordiformis*) and green ash were the most common associates of the oak species. The oak forest had an estimated density of 421 trees/ha, a compositional index of 543, and a Simpson's Diversity Index of .826. Hackberry, basswood, and black cherry (*Prunus serotina*) were abundant, although black cherry was found most often as a sapling. There were scattered individuals of large, older white pines near the north end of the island, and American elm, red cedar, and silver maple were common. A few individuals of sugar maple (*Acer saccharum*) were also found in the oak forest at the lower elevations. Yellow bud hickory saplings were abundant, and hackberry, cherry, and basswood saplings were also common. Red oak was the most common of the oak saplings present

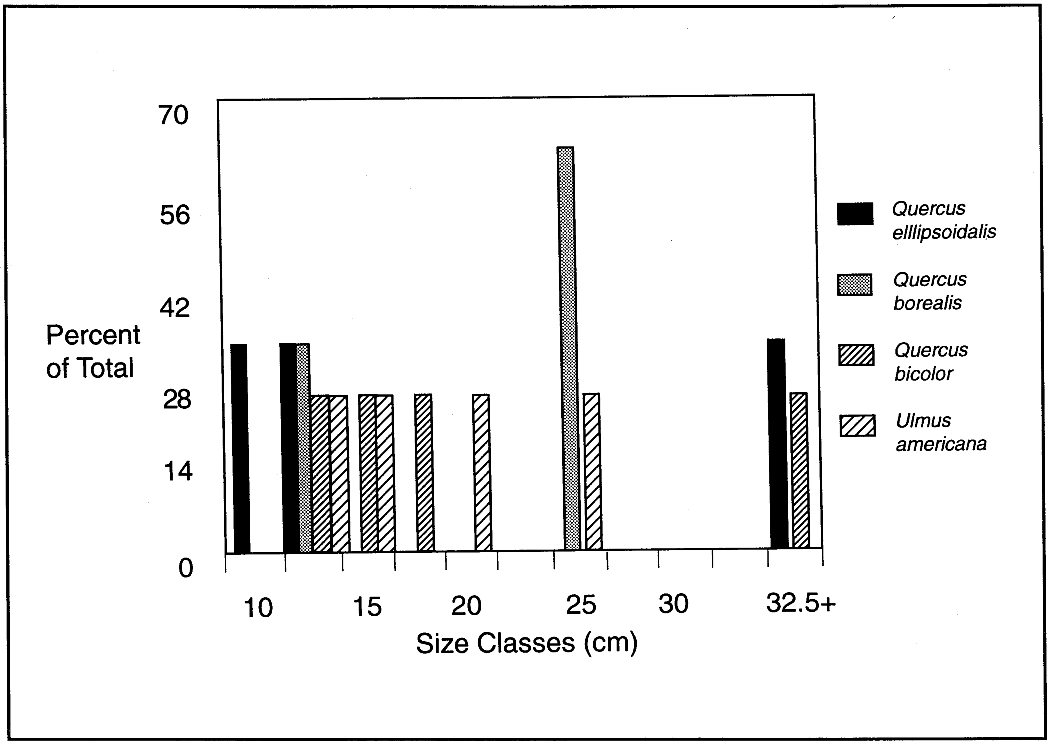

Fig. 5. Size class distribution of four important tree species in Oak Opening II

with fewer white oak and bur oak saplings. The comparative size distribution suggests continuation of the oak forest, but as shown by the numbers of young trees present, it appears that red oak may continue to dominate in the future (Fig. 6), and white oak and basswood populations appear stable. Prickly ash, prickly gooseberry, grey dogwood, and red osier dogwood (*Cornus stolonifera*) were common shrubs in the understory. Staghorn sumac was also present, although less abundant than in the oak openings. Rye grass and bottlebrush grass (*Hystrix patula*) as well as woodland nettle (*Laportea canadensis*), *Aster* sp., and wild geranium (*Geranium maculatum*) were abundant throughout the oak forests.

Hackberry and green ash were the largest and two of the most abundant of the fifteen species of trees in the mesic forest and had as close associates basswood (the most abundant tree species) and yellowbud hickory (Table 7). Curtis (1959) described basswood and red oak as dominant species of mesic forests. This community occurs over much of the central part of the island at an elevation of 1.5 to 2.1 m (4.9 to 6.5 ft) above the normal level of the river. There are some places where the land is low and contains marshes. The soil is sandy loam, with an isolated patch of silty loam, and has a high percentage of organic matter and a relatively high water-retaining capacity. This community had an estimated density of 338 trees/ha, a compositional index of 659, and a Simpson's Diversity Index of .828. American elm and white oak were also common. Hop hornbeam (*Ostrya virginiana*) occasion-

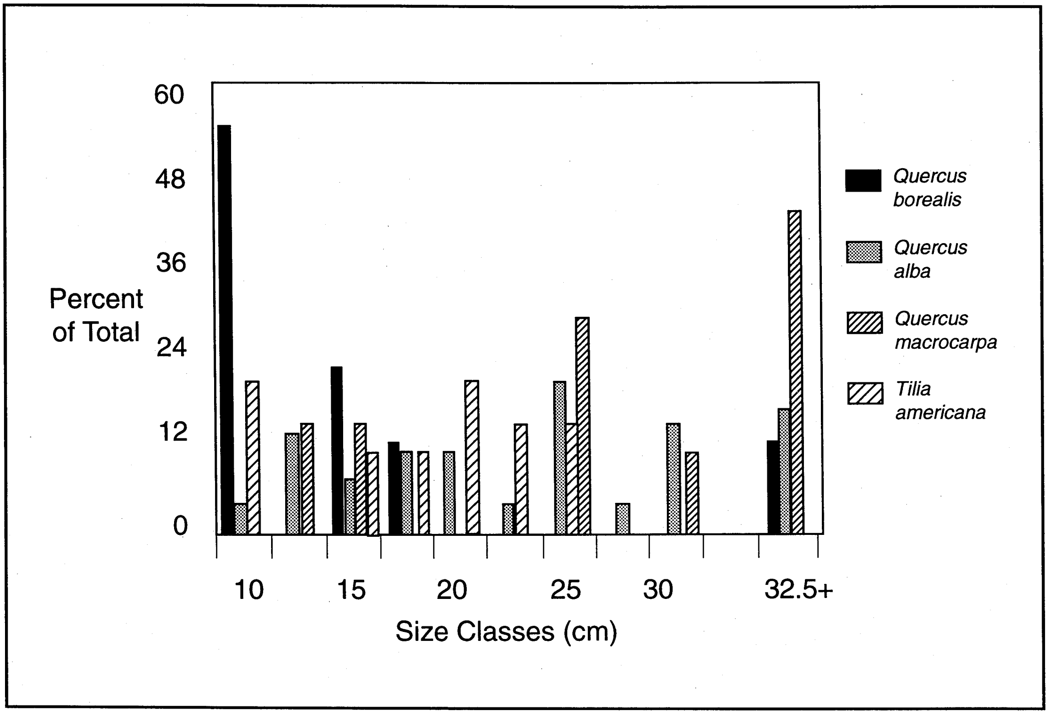

Fig. 6. Size class distribution of four important tree species in the Oak Forest

Table 5. Frequency (%F), mean diameter (x̄dbh), relative density (%RD), and importance values (IV) of trees in Oak Opening II (11 quadrats, 20 trees)

Species	*%F*	*x̄dbh (cm)*	*%RD*	*IV*	*Sapling Frequency (%)*
Quercus alba	45.5	21.3	10	14.8	54
Quercus bicolor	36.4	20.0	20	20.4	30
Quercus ellipsoidalis	36.4	20.0	15	17.8	60
Ulmus americana	18.2	18.1	20	15.3	25
Quercus borealis	18.2	20.8	15	13.7	50
Fraxinus pennsylvanica	18.2	22.5	5	6.8	60
Celtis occidentalis	9.1	16.3	10	7.3	60
Juniperus virginiana	9.1	12.5	5	3.9	20

Table 6. Frequency (%F), mean diameter (x̄dbh), relative density (%RD), and importance values (IV) of trees in the Oak Forest (20 quadrats, 81 trees)

Species	*%F*	*x̄dbh (cm)*	*%RD*	*IV*	*Sapling Frequency (%)*
Quercus alba	78.9	25.5	37.1	32.1	35
Carya cordiformis	42.1	12.5	1.2	4.5	75
Fraxinus pennsylvanica	36.8	29.5	6.2	8.3	50
Quercus borealis	31.6	14.7	11.1	8.2	45
Celtis occidentalis	31.6	32.5	3.7	6.3	60
Prunus serotina	21.1	13.7	2.5	3.1	55
Tilia americana	21.1	19.8	12.4	8.6	60
Quercus macrocarpa	15.8	30.4	8.6	8.9	30
Juniperus virginiana	15.8	16.3	4.9	3.8	50
Acer saccharinum	15.8	37.5	2.5	4.3	45
Quercus ellipsoidalis	10.5	27.5	4.9	4.7	60
Ulmus americana	10.5	17.5	1.2	1.6	55
Acer saccharum	10.5	12.5	1.2	1.5	60
Pinus strobus	5.3	48.8	2.5	4.2	30

Table 7. Frequency (%F), mean diameter (x̄dbh), relative density (%RD), and importance values (IV) of trees in the Mesic Forest (83 quadrats, 284 trees)

Species	*%F*	*x̄dbh (cm)*	*%RD*	*IV*	*Sapling Frequency (%)*
Celtis occidentalis	51.8	20.8	18.3	17.6	70
Fraxinus pennsylvanica	43.4	23.8	19.7	18.4	50
Carya cordiformis	40.9	12.1	8.8	9.2	90
Tilia americana	36.1	26.8	28.9	26.3	65
Ulmus americana	20.5	19.8	7.8	7.0	30
Quercus alba	16.9	27.9	5.6	6.6	30
Acer saccharinum	10.8	41.7	3.2	5.6	25
Ostrya virginiana	8.4	20.0	2.5	2.6	30
Quercus borealis	7.2	35.6	1.4	2.4	20
Quercus ellipsoidalis	2.4	24.2	1.1	1.0	25
Quercus macrocarpa	2.4	42.5	.7	1.2	25
Carpinus caroliniana	1.2	46.3	.7	1.1	—
Prunus serotina	1.2	13.8	.7	.5	30
Ulmus thomasi	1.2	12.5	.4	.3	10
Ulmus rubra	1.2	10.0	.4	.3	15

ally occurred as saplings or small trees, and silver maple was often found in low lying areas. Yellowbud hickory saplings occurred in almost every quadrat, while hackberry and basswood saplings were also common. In the mesic forest, it appears that green ash and basswood may replace silver maple (Fig. 7). Also, white oak is an important species, and while some of the older trees may be replaced, there are many white oak saplings present to suggest that white oak will remain an important species. Shrubs included prickly ash, prickly gooseberry, red and grey dogwood, and an occasional thornapple (*Crataegus* sp.). Blackberry (*Rubus allegheniensis*), raspberry (*Rubus* sp.), and the vining and climbing species virginia creeper (*Parthenocissus quinquefolia*) and grape (*Vitis riparia*) were abundant in the forested areas. Rye grasses were also common in the less shaded areas of the mesic forest.

Silver maple was the largest and most abundant of the nine species of trees in the floodplain forest (Table 8). Its major associates were green ash and American elm. Basswood was often abundant on higher ground while clumps of river birch were found in the lowest areas. Silver maple, American elm, or ash are often dominant in floodplain forests in Wisconsin (Curtis 1959).

The floodplain forest occurs primarily on the western end of the island with an isolated patch in the central part. The average elevation is from .9–1.2 m (2.9–3.9 ft) above the normal level of the river, which makes this community prone to frequent flooding. The soil is silty, poorly drained, and some-

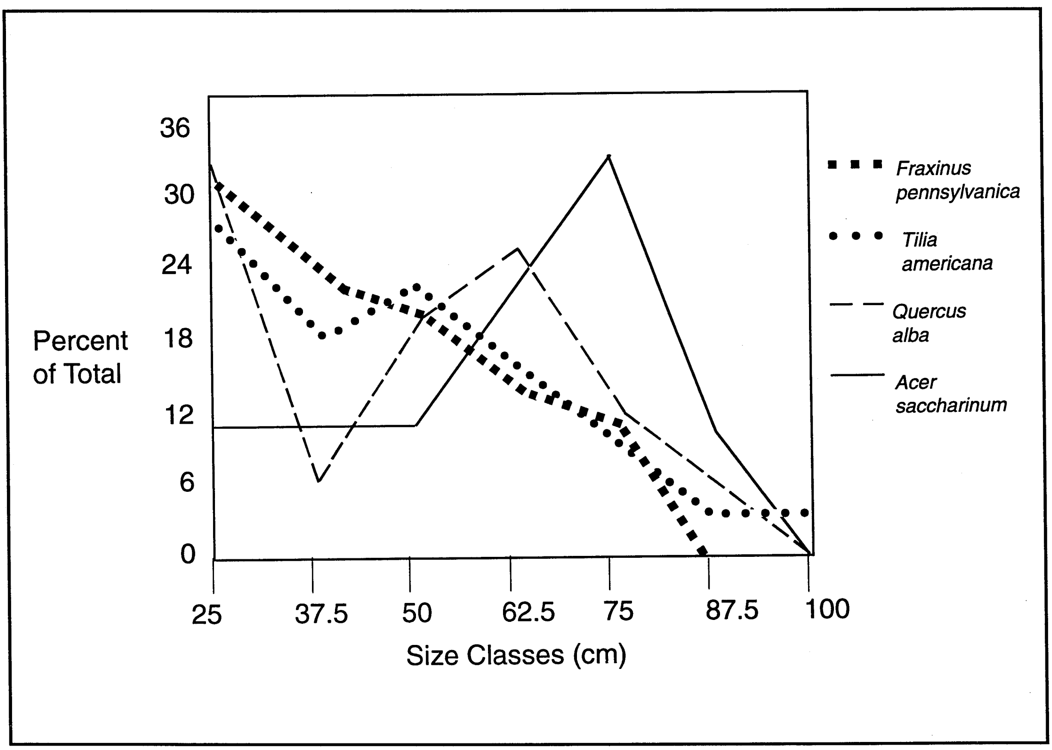

Fig. 7. Relative peak values of four important species of the Mesic Forest

what lower in organic matter than the mesic forest. These soils are higher in water-retaining capacity than the soils of other community types on the island. The floodplain forest had a lower number of tree species than the mesic forest and had an estimated density of 325 trees/ha, a compositional index of 507, and the lowest Simpson's Diversity Index of .712. It had a high estimated basal area per ha of 47,267 cm^3 because of the many large, apparently older trees. Hackberry and slippery elm (*Ulmus rubra*) were common, and occasional, mature individuals of bur oak were also present. Hackberry and basswood saplings occurred in almost every quadrat, while green ash and American elm saplings were also common.

In the floodplain forest, it appears that green ash may eventually be replaced by American elm, although that seems unlikely because of Dutch elm disease, and some of the large, older silver maples may be replaced by green ash (Fig. 8). Prickly ash was present throughout the area, although generally the floodplain forest was more open and had few shrubs. Rye grass was abundant in less shaded areas, and virginia creeper, wild yam (*Dioscorea villosa*), and grape were common vines.

Community-Environment Relations

The result of the ordination shows the distribution of the communities in a two-dimensional space (Fig. 9). The distance between the positions of communities along the x-y axes represents the degree of compositional difference between them. The five

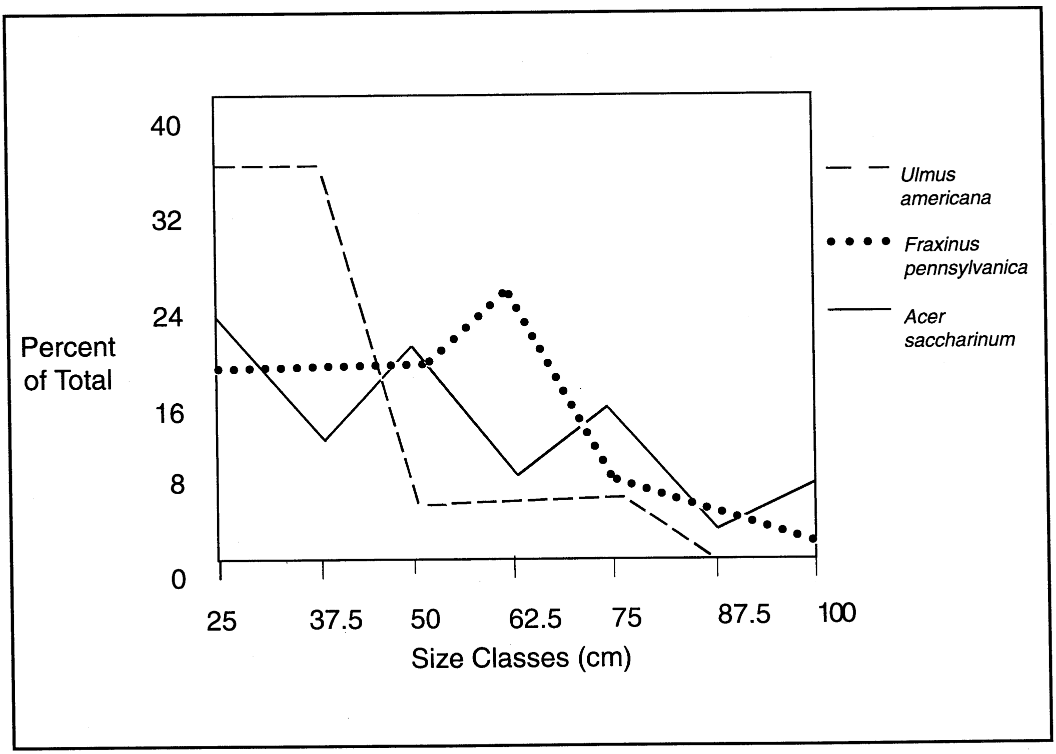

Fig. 8. Relative peak values of three important species of the Floodplain Forest

communities form two distinct groups, the oak openings and oak forest in one group and the mesic forest and floodplain forest in a second. The grouping appears to be related to several environmental factors. The oak openings and oak forest occur at the higher elevation where there is a lower water-retaining capacity and higher sand content, while the mesic forest and floodplain forest occur at the lower elevation where there is a high water-retaining capacity and lower sand content.

The communities at higher elevations have lower water-retaining capacities because of higher percent sand and lower organic matter content, while the mesic forest and floodplain forest at lower elevations have higher water-retaining capacities because of higher organic matter content and lower percent sand. The evident interrelationships between the environmental factors are shown in Table 9. The percentage of sand is positively correlated to elevation, and there is also a strong positive correlation between percent of organic matter and water-retaining capacity (Table 10). Elevation and percent organic matter do not appear to be correlated, while there is a negative correlation between increasing elevation and water-retaining capacity. It should be noted that there were only five sets of data, and with the resultant low number of degrees of freedom, none of the values obtained were found to be statistically significant above a 90% level of confidence.

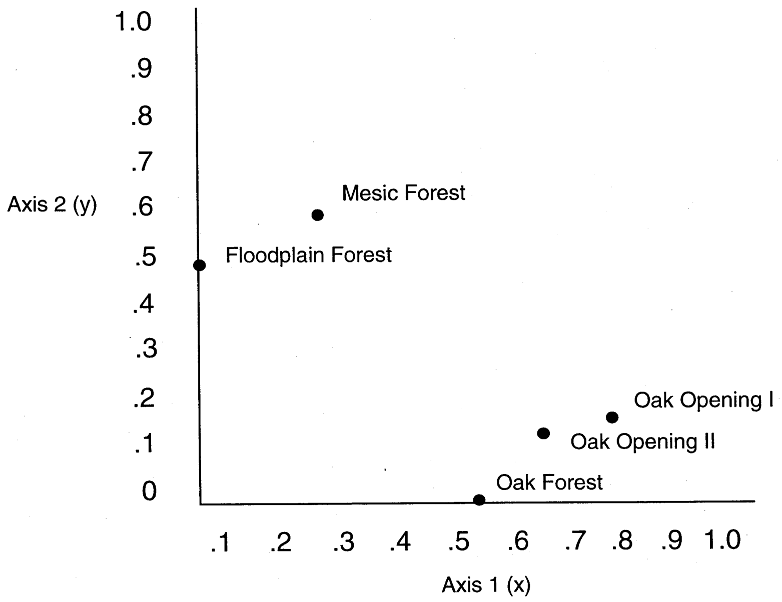

Fig. 9. A two-dimensional polar ordination of the five communities by importance values

Table 8. Frequency (%F), mean diameter ($\bar{x}$dbh), relative density (%RD), and importance values (IV) of trees in the Floodplain Forest (31 quadrats, 102 trees)

Species	*%F*	*$\bar{x}$dbh (cm)*	*%RD*	*IV*	*Sapling Frequency (%)*
Acer saccharinum	58.1	35.3	45.1	45.8	60
Fraxinus pennsylvanica	41.9	27.2	24.5	21.6	65
Ulmus americana	32.3	17.9	16.7	13.2	60
Celtis occidentalis	22.6	18.3	2.9	5.4	95
Tilia americana	9.7	33.3	2.9	3.7	95
Betula nigra	9.7	25.8	2.9	3.4	15
Quercus macrocarpa	6.4	47.5	1.9	3.3	25
Ulmus rubra	3.2	33.8	1.9	1.9	20
Populus deltoides	3.2	55.0	1.0	1.8	—

Table 9. Soil water-retaining capacity (% WRC), sand (% S), organic matter (% OM) and elevation (m) of each of the five communities (18 samples)

Community	*% WRC*	*% S*	*% OM*	*Elevation (m)*
Oak opening I	96.21	72.44	12.49	2.43–3.03
Oak opening II	103.61	80.0	18.66	2.43–3.03
Oak Forest	119.7	66.7	12.0	1.83–2.43
Mesic Forest	141.11	67.8	34.67	1.52–2.13
Floodplain Forest	160.03	63.42	30.80	.91–1.22

Table 10. Correlation coefficient values (r) for physical environmental factors examined in the study

	Elevation	% Sand	% WRC	% Organic matter
Elevation	1.0	.56	-.79	-6.4
% Sand	.56	1.0	-.78	-.69
% WRC	-.79	-.78	1.0	.65
% organic matter	-.0064	-.69	.65	1.0

Discussion

The original survey records indicate that the island was about 93% forested prior to settlement (Fig. 10). About 30% of the area was floodplain forest, 50% was mesic hardwood forest, and 20% was oak openings.

Early settlement and the limited use of the island for agriculture had little apparent impact on the forests. Human activities were limited to a small woodcutting operation on the central part of the island and use of the open prairie area for agriculture. There was a small farmstead on the eastern end of the island in the oak opening/prairie area on which crops were raised. This farm dated back to the late 1800s and was in use until the 1940s according to a personal account (Hubbard, pers. comm., 1991). Hay and grasses were raised for forage in the open areas, especially during the depression years and early 1940s. No other evidence suggests use of the open areas for crops although cattle grazed in a fenced pasture of about 202 ha (500 acres) on the prairie. Remnants of the old fence are still visible. Pasturing may account for what seems to be an increase in the extent of the oak openings/prairie area since the 1940s.

The present composition of the forests is similar to that of 1848. The same overall configuration of plant community types was observed on the island in the autumn of 1990 as were described in the original land survey records. The only change is that there appears to be more open land occupied by prairie vegetation. This may be a result of the use of the land for pasture or simply the lack of precision when working with the 1848–49 data.

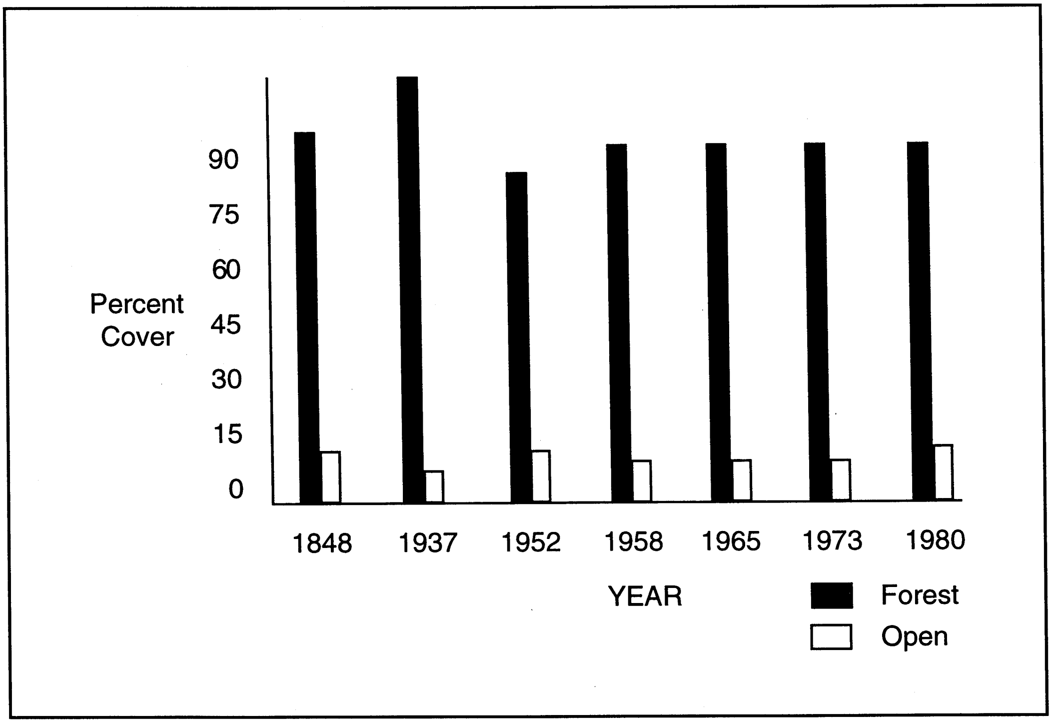

Fig. 10. Changes in vegetation cover from 1848 to 1980

Elevation appears to be the major influence on the development of plant community types on this island as it is related to flooding frequency and to soil texture as well as to organic matter content and water-retaining capacity of the soil. Major changes in the topography of the island are not likely to occur; thus, significant changes in the vegetation are unlikely in the future. Also, a high frequency of saplings and small trees of the most abundant species in the oak openings and oak forest suggests little probable change in their tree composition in the foreseeable future. In the mesic forest and floodplain forest relative peak value summaries of the dominant species suggest that there may be some successional changes. However, such changes are likely to be small and gradual and not have a pronounced effect on the overall type and extent of these forests.

There is a note of urgency to the WDNR's current process of acquiring the island as a State Natural Area. Parts of the original floodplain forest remain threatened by logging operations. In the past decade about 202 ha (500 acres) of floodplain forest timber currently owned by the Schlosser Lumber Company have been either select-cut or clear-cut, removing about 40–60% of the canopy cover (Epstein, pers. comm., 1990).

Most studies of vegetation history in Wisconsin have examined upland areas and have reported drastic changes in the vegetation as a result of man's activities (Gleason 1913; Curtis 1959; Stroessner and Habeck 1966; Barnes 1974). However, extensive changes in the nature of the vegetation of Nine-Mile Island have not occurred. The only effect of human impact in the past has been in the form of minor woodcutting for fuel (with available equipment, it is probable that only trees 20 cm dbh or smaller were harvested), pasture for dairy cattle in the open areas of the island, and crops raised on a small farm in the same area. Only the barn foundation of the old farmstead remains. The only human habitation on the entire island is a hunting cabin on the site of the old farmstead. Isolation on this island with its low elevation and undeveloped soil types have maintained these communities in their original state. Nine-Mile Island is a unique ecological resource containing rare plant and animal species and is a good example of a lowland forest habitat which should be preserved in its nearly pristine state for the enrichment of future generations.

Acknowledgments

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Keith T. Weber

Analysis of black bear habitat in northeastern Wisconsin

Abstract *A study was performed in northeastern Wisconsin from June through December 1991 to analyze the regional habitat and density of black bear* (Ursus americanus). *Previously reported habitat requirements of the black bear were used to establish areas that might be successfully exploited by bears within a proposed 259.2 km² (100 mi²) study site. The field study area contained moderate to good black bear habitat estimated to carry a bear population density of one bear/6.1 km² based on roadside counts.*

Black bear (*Ursus americanus*) research by the Wisconsin Department of Natural Resources (WDNR) and the University of Wisconsin–Stevens Point has focused recently in the north-central and northwestern portion of the state (Kohn 1982; Anderson, pers. comm.). My study in northeastern Wisconsin was initiated to determine the present population of black bear and to assess habitat quality. The results of this study will aid in the understanding and management of the bear.

The study began on 1 June 1991 and terminated on 2 December 1991. Known black bear habitats with varying population densities from around the United States and Canada revealed several key features, including soil characteristics, forest type and age of stand, altitude, and the effects of timber harvest, agricultural activity, hunting pressure, human population density, and the road-to-forest ratio. Generally, black bears require habitat containing a soft-mast food source (e.g., berries) and a hard-mast food source (e.g., nuts and acorns) (Rogers and Allen 1987) accompanied by forested cover (Unsworth et

Table 1. Comparison of various black bear population studies

State	*Forest Composition*	*Human Density (per km²)*	*Bear Density (1/X km²)*	*Reference*
California	Pine and fir	0.93	1/1.3	Piekielek and Burton 1975
Idaho	Shrub and pine	0.95	1/1.3	Beecham 1983
Minnesota	76% aspen, 24% spruce	8.30	1/5.2	Rogers 1987
New York	Unavailable	29.10	1/17.1	McCaffrey et al. 1974
Wisconsin	N central, 90% forested	5.47	1/3.9	Kohn 1982
Wisconsin	NE, 87% upland, 7% lowland	11.00	1/6.1	(this study)

Human population density figures were taken from the U.S. Census Bureau reports and reflect the population at the time of the bear study. Bear densities are the mean of the estimated population range given in the study (e.g., a study performed by Rogers [1987] reported a black bear density of one bear/4.1–6.3 km². The value used above was the mean of 4.1 + 6.3 [$\bar{x}$=5.2]).

al. 1989). Bear populations range from one bear/1.3 km² in California (Piekielek and Burton 1975) to one bear/17.1 km² in New York (McCaffrey et al. 1974) (Table 1).

My research was conducted to (1) determine the population of black bear in a local study of northeast Wisconsin, (2) assess habitat quality, and (3) compare the study site with the findings from other black bear studies.

Study Area

Field work was conducted in a 259 km² (100 mi²) region in northeast Wisconsin, located in the southwest corner of Marinette County. Throughout this paper the study site will be called the Marinette County Study Area (MCSA) (Fig. 1). Elevation ranges from 412 m (1350 ft) above sea level to 229 m (750 ft), with the mean elevation extending from 274–305 m (900–1000 ft). Soils in this region are primarily sand, with the Menagha association (70%) and the Mancelona-Emmet Menagha associations (15%) being most prevalent. Seven percent of the region is a Seelyville Markey association with 2.5% each of the Sarona-Keweenaw and Ishpeming-Michigamee associations. The majority of these soils were created from glacial outwash and till (87.5%) (Lorenz 1991). The remaining 3% of soils is flooded by the High Falls reservoir and Thunder Lake. Several streams, small lakes, and ponds are not mentioned or included in the above data.

The rock outcroppings in the Ishpeming-Michigamee soil association can provide good den sites for the black bear (Lorenz and Thrall 1991), but bear usage of these rock outcroppings, while not common, is more typical of pregnant sows than boars (Jackson 1961; Fair 1990). Much of this area is wooded, providing the black bear with forage, the bulk of which can be found on well-drained uplands containing oak, hazelnut, and berries (*Quercus* spp., *Corylus* spp., and *Rubus* spp., respectively). The MCSA consists of 90% well-drained soils, of which 87% is forested uplands (*Populus* spp., *Pinus* spp., and *Quercus* spp.), 7% is lowlands (*Fraxinus nigra, Acer rubrum, Thuja occidentalis,* and *Picea mariana*), and 3% is rock outcroppings (Couvillion 1990) (Figs. 2 and 3).

Forest composition in the MCSA is similar to that published for the property within the MCSA owned by the regional utility company, Wisconsin Public Service Corporation (WPSC). The WPSC property adja-

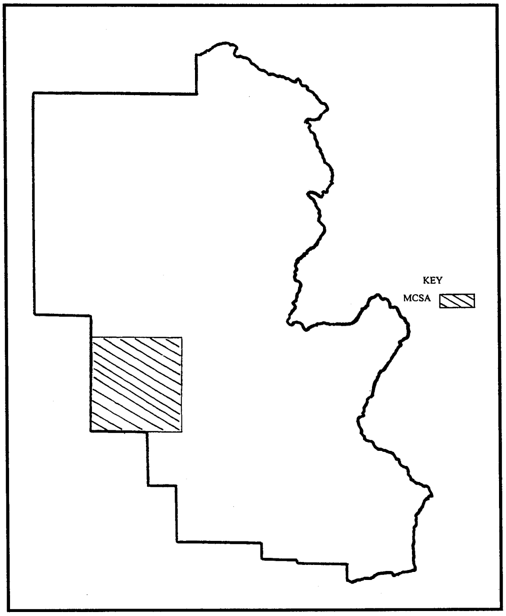


Fig. 1. The location of the Marinette County Study Area (MCSA) in northeast Wisconsin

cent to the High Falls reservoir is composed of 86.8% uplands and 6.7% lowlands; the balance is unforested (WPSC 1991). The MCSA exhibits homogeneity in soil features and forest composition.

Privately owned land accounts for 65% of the study area. Public land comprises 25% while the remaining 10% belongs to WPSC (Land Atlas and Plat Book 1985). Forest inventory maps were made available by the WDNR and WPSC for all public and utility land, respectively. Forest composition of the entire MCSA was approximated by correlating forest inventory maps with the Marinette County soils maps and topographic maps.

Agricultural land comprises 19% of the county (Decker, pers. comm.). A few large tracts of forest exist, but forest edge is extensive in the region because of substantial logging. Studies performed in Idaho suggest that black bears prefer 20–40-year-old stands of timber that have not been previously clear cut. Unsworth et al. (1989) and Fair (1990) found that bears tend to avoid those areas that have sustained a clear cut of 20 or more acres. The age of the stand was considered when evaluating habitat quality.

The use of sanitary landfills by bears has been noted in other papers (Kohn 1982; Rogers 1987), but such areas are absent in the MCSA. An intensive study zone of 30.72 km^2 (12.0 mi^2) was established within the MCSA to provide a better perspective of the study area. The intensive study zone is delineated in Figures 2 and 3. The majority of field research was conducted on public land. Nevertheless, I shall assume that the results found in the intensive study zone are applicable to the entire MCSA due to the homogeneous nature of the soil and forest features found throughout the region.

Materials and Methods

The research conducted in this study pertains to the *americanus* subspecies of the black bear (*Ursus americanus*) which occurs throughout northern Wisconsin and is typically of the black color morph (98%) (Rounds 1987). For this paper, adult bear refers to a bear at least four years old, subadult to one between the ages one and four, and cub to one less than one year old (Rogers 1987). Henceforth, a female will be referred to as a sow and a male as a boar.

Information on forest inventories was provided by the WDNR (mapped by Couvillion) and the WPSC. Supplementary forest surveys were conducted to provide an enhanced picture of the study area and to provide ground truth with the WDNR-Couvillion forest inventory. I used the point-quarter method (Smith 1974) to establish an independent description of vegetation which

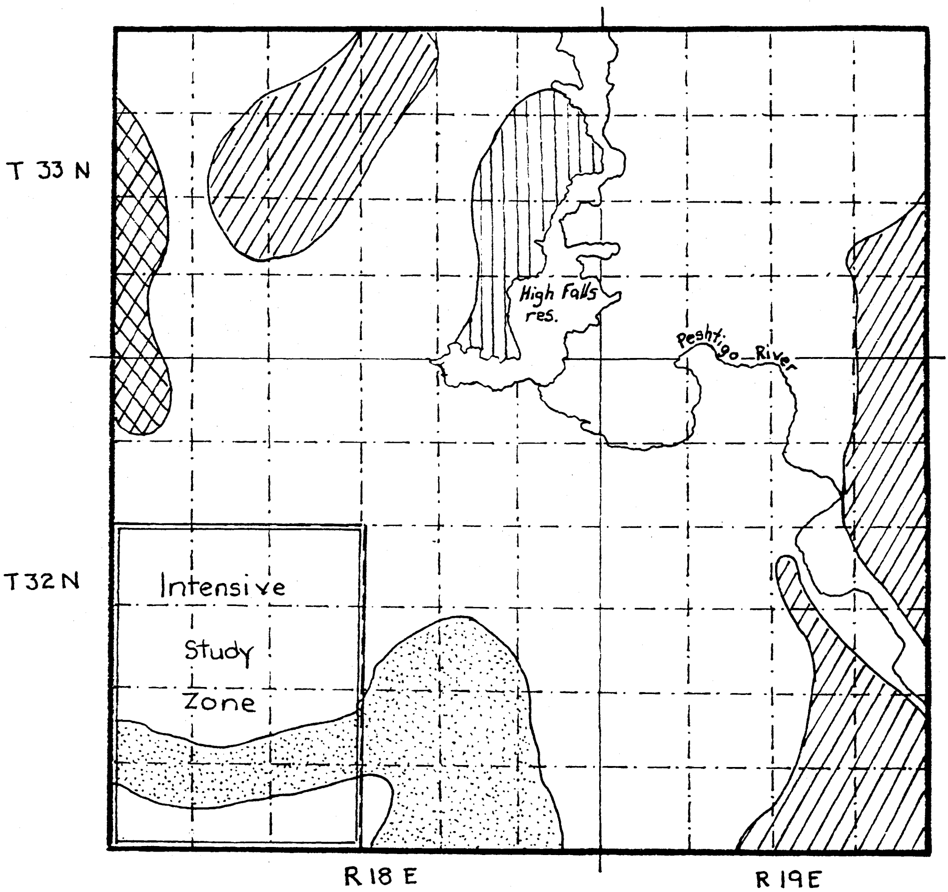
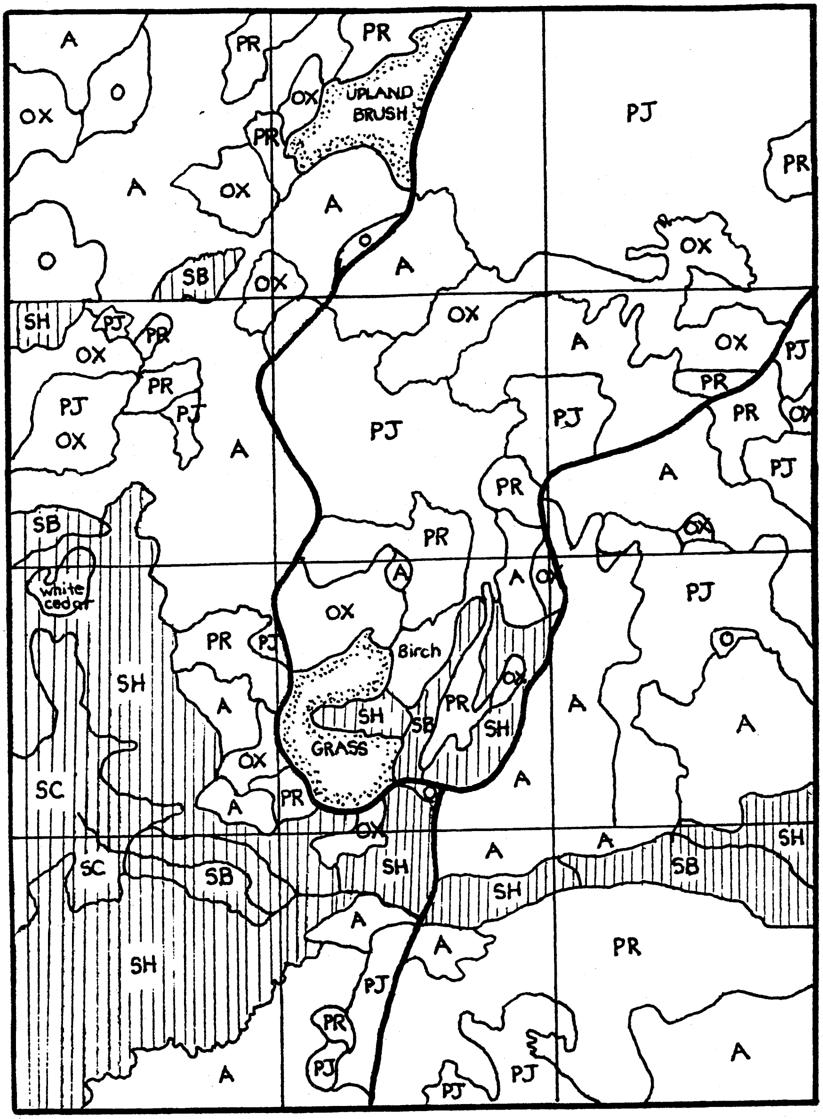


Table of Soil Percentages			Scale
Well Drained	Poorly Drained	%	
From Glacial till			1 mile
Sarona Keewana		2.5	1 km
From Glacial Outwash and till			N
Mancelona Emmet Menagha		15.0	
Menagha		70.0	
Ishpeming Michagamee		2.5	
Organic Soils			
	Seelyville Markey	7.0	

Fig. 2. Map of soils found within the MCSA and the delineation of the Intensive Study Zone



Forest Inventory of MCSA (WDNR, WPSC)				Upland Forest Sampling	
%	Species	Upland	Lowland	Species	Rel Dens
87.0	Aspen(A), Jack Pine (PJ)	*		Red Oak	22
	Scrub Oak(OX), R Pine(PR)			Aspen	19
7.0	Blk Ash/ Red Maple(SH)		*	White Pine	16
	Cedar/ Spruce/ Fir(SC)			Red Pine	13
	Blk Spruce(SB)			Red Maple	13

Fig. 3. Map of forest composition found in the Intensive Study Zone and Forest Inventory Table for the MCSA

could then be compared with WDNR forest inventory maps; the results showed similarities between the two vegetation descriptions. Eighty quadrats were sampled along two transects, resulting in a 2.5 m (8.2 ft) mean point-to-plant distance and a mean area per individual of 6.25 m^2 (67.24 ft^2) (Fig. 3).

Bear populations were estimated by roadside count of tracks, droppings, and visual observation. Note that roadside counts do not generally represent actual populations but are an index to the population and are indicative of population trends. However, because of the characteristic low population density and sexual dimorphism of the black bear and the relationship between bear weight and track size (demonstrated by Piekielek and Burton [1975]), an estimate of the bear population in the intensive study zone could be made with ample time spent in the field. Counts were performed by vehicle once per week for twelve weeks over a 26 km route (n= 12, 25.9 km/ week [10 mi/ week]). The same route was driven on each occasion, although minor deviations were allowed and were sometimes necessary based on road conditions. The number of distinct bear sign observed was divided by the distance traveled. Only those tracks unquestionably made by a black bear were counted. When a set of tracks was found, the most distinct front and rear prints were chosen as samples, and measurements were taken of pad length, pad width, and width across the toes. The sum of the six values is the composite foot measurement and can be used to determine the approximate live weight of a bear (Piekielek and Burton 1975; Kohn 1982). Additional data collected included direction of travel, the soil type in which the track was made, the time when the track was found, and the precise location of the prints (Smith 1974). I estimated the age of the tracks, the distance the animal traveled on the forest road, and its speed of travel. The location of each bear was determined in the field and later plotted on a topographic map to help distinguish individuals and to better understand the home range of bears in the MCSA.

Results

The study of tracks located during the roadside count suggested that five bears (three adults/sub-adults, two cubs) inhabit the intensive study zone of the MCSA. This is the known minimum population (P_k), determined by comparing track size and weight estimates derived by using composite foot measurements. Individuals were recognized by variations in track size that could not be attributed to speed of travel or the soil medium. The P_k of five bears/30.7 km^2 yields a density of one bear/6.1 km^2 for the MCSA. Standard deviation of the road side counts was determined according to the formula

$$S = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}}$$

where x_i represents the number of bears located in the intensive study zone during one time period, $\bar{x}$ is the mean number of bears located during the weekly count periods, and n is the total number of weekly roadside counts ($\bar{x}$ = 3.67, s = .58, n = 12).

Comparison of the P_k and the WDNR-estimated black bear population density for Wisconsin's bear range (P_p = 1/ 3.8 km^2 [1/ 1.5 m^2]) revealed a slightly lower population in the MCSA. The WDNR has created three black bear management zones within the bear's range across the northern third of the state (i.e., zones A, B, and C). The MCSA lies in management zone B, which the WDNR estimates to have a population density of P_p. The basis of the variation can be illustrated by examining several factors: (1) The MCSA is a relatively small region within bear management zone B. Therefore, various population density estimates should be anticipated when sampling subsets of a larger region (Amundsen, pers. comm.). (2) A higher human population weighs heavily against bear numbers, as a negative correlation seems to exist between the two factors (Kohn, pers. comm.). The general agreement between these patterns and the conditions in my study area supports the results obtained by this study.

Initially the results of the weekly counts (x_i) were alike, but as the autumn proceeded, bear sign diminished. This probably was due, at least in part, to the pressure exerted on the bears by hunting, perhaps causing them to avoid roads during the bear hunting season (September–October). The reduction could also be related to a diminished amount of available food and the onset of hibernation. A distinct drop in bear sign was evident on 14 October; this trend continued until the roadside counts were terminated on 28 October. For this reason, I have limited my calculations from roadside counts to the period prior to 14 October 1991. The roadside count index for 1991 is .217 bears per kilometer of road traveled.

At least one boar is known to inhabit the intensive study zone. A set of large tracks (length of hind print = 267 mm [10.5 in]) was discovered in mid-September and, due to size alone, the possibility of the tracks being made by a sow was eliminated. Research indicates that the hind print of a sow rarely exceeds 240 mm (9.5 in) (Trauba, pers. comm.; Jackson 1961). These tracks were no more than a few hours old (a strong downpour had occurred earlier that morning) and made in soft sand. The weight of the boar was approximated by employing the method detailed by Piekielek and Burton (1975) using composite foot measurement (800 mm [31.5 in]) to determine the live weight of the animal. The boar's weight is approximated at 147 kg (327 lb).

Discussion

Bears use forest roads as a means of travel. The observed tracks indicate that bears tend to follow the road for some distance (in one case for over 200 m) rather than simply cross the road. The bears that used the roads nearly always traveled on the road edge and in the same direction as vehicular traffic flow. This appears to contradict the findings of Unsworth et al. (1989) who reported that black bears rarely used roads as travel routes. However, since an estimate of the number of bears that avoided roads was not known, I cannot infer that all black bears in the study area regularly use roads.

Two possible den sites were located in the intensive study zone, both beneath the roots of upturned trees (*Tsuga canadensis* and *Thuja occidentalis* L.). One site was neatly cleaned and contained the tracks of a sow with one cub, believed to be the same family indicated earlier, although the tracks from her second cub were not found (Fig. 4). Black bears in the MCSA presumably use ground-level dens because the mean January temperature is -11.4°C (11.4°F) (Lorenz 1991) and excavated black bear dens occur less frequently unless the mean January temperature falls below -20°C (-4°F) (Tietje and Ruff 1980).

To evaluate the vitality of the bear population in the MCSA, data regarding reproduction was necessary. As mentioned previously, one sow is known to have given birth to two cubs that were still alive in early October 1991. Results of the 1991 mating season are unknown. However, signs of activity by area boars, including the presence of

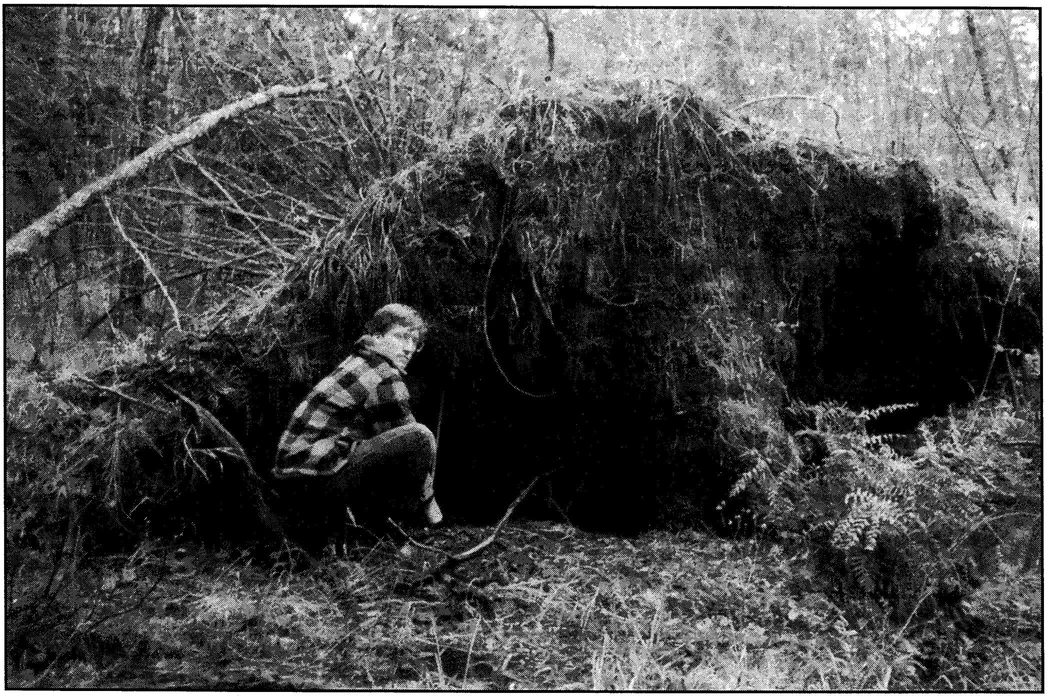


Fig. 4. The author is shown investigating an overturned cedar where the tracks of a sow and one cub were found. It is not certain if bears will use this site for denning purposes as it is susceptible to spring flooding.

"bear trees," indicates that some competition for mates may have occurred.

Black bears, especially adult boars (85%), use trees as marking posts during the June mating season, presumably to communicate their presence to other males (Laycock 1988; Rogers 1987). Further, Rogers found that utility poles were also used for marking purposes. The power line which cuts through the intensive study zone was closely examined for bear sign. All utility poles examined (n = 30) were constructed of large southern yellow pine (*Pinus palustris*), and one was positively identified as having been marked by a bear (Fig. 5). This determination is based on (1) the manner in which it is marked, which corresponds well with typical marking behavior (predominately openings or edges with markings toward the opening), (2) five individual claw marks evident in each stroke (width = 133 mm [5.25 in]) reaching a height of 2.12 m (83.25 in), and (3) six black hairs (length = 20–65 mm) removed from the pole between a height of .61–1.27 m (24–50 in). Because these hairs suffered little bleaching from the sun, one may conclude that this pole was marked during the 1991 mating season (Rogers 1987).

The availability of forage for bears in the MCSA was studied in the field to help determine the quality of black bear habitat provided by this area. Whereas an abundance of soft-mast food was available, oak mast (acorn) production for fall 1991 failed throughout the county, perhaps because of stress from previous years of drought, damage caused by the tent caterpillar (*Malacosoma constrictum*), and injury from oak wilt. The effect of oak mast failure is not known at this time, but the abundance of berries should alleviate this stress. A study by Elowe and Dodge (1989) indicates that if sows become nutritionally stressed, >66% of potential mothers could reabsorb the blastocyst and come into estrus again the following season. Another study (Fair 1991) suggests that reproductive synchrony could result from mast crop failure.

The mean age of the black bear population is a concern in bear management. Studies in Montana by Jonkel and Cowan (1971) reveal that the black bear does not reach sexual maturity until it is 3.5 years old. This is further supported by the findings of Rogers (pers. comm.) and Anderson (pers. comm.) in Minnesota and north-central Wisconsin, respectively. Furthermore, a sow may not breed until it is four years old and, in some cases, the sow will not successfully raise a litter until it is more than six years old. Therefore, a healthy bear population is expected to have a mean age of 4–5 years (Laycock 1988). While a relatively young population (mean age 4.1 years) presently exists in the MCSA (Kohn 1982), the number of sub-adults is estimated to be high, and these bears are projected to carry the population to an older mean age (Amundsen, pers. comm.). Thus, the age structure of the bear population in the MCSA appears to be healthy.

Bear populations can be affected by numerous factors such as development and road construction, which tend to fragment the population and produce "islands" of bear habitat isolated from one another by regions of unsuitable habitat. Research indicates that the "black bear cannot function as a population" when its density drops below one bear/25.9 km^2 (1/10 mi^2) (Fair 1990). The bear population density in the MCSA (one bear/6.1 km^2) is much higher than this "threshold level," indicating that, currently, the black bear population in the MCSA is healthy and that the quality of habitat is adequate to support this population into the foreseeable future. This is based on the following evidence: (1) the bears are known to be reproductively active, (2) various forage exists in the region offering alternative food sources in the event that one source should fail, (3) the mean age of the population is 4.1 years (black bears in northeast Wisconsin are sexually mature at 3.5 years), and (4) estimated population densities are high enough to sustain a viable population as defined by researchers elsewhere (Fair 1990; Laycock 1988).

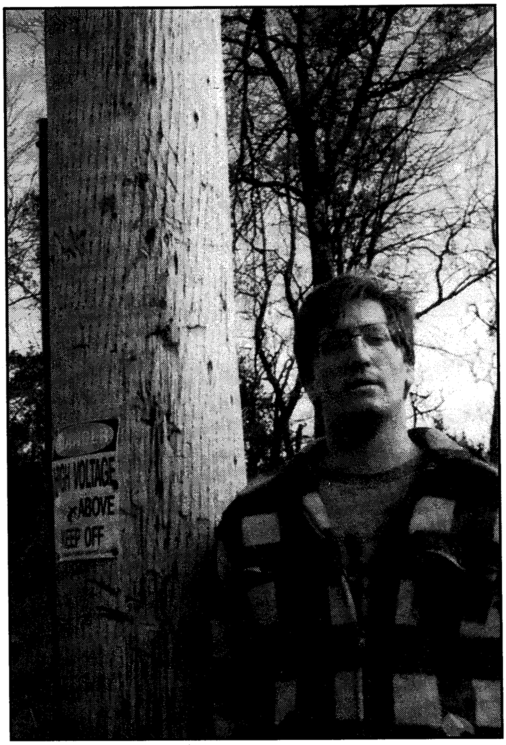


Fig. 5. This photograph shows a utility pole which was used by a boar, presumably to signal his presence to other bears. The author is shown here to better illustrate the height of the marks.

The population estimate of one bear/6.1 km^2 is lower than the WDNR estimate (one bear/3.8 km^2), probably because of the following factors rather than a decline in bear population or discrepancy in population estimates: (1) the MCSA is only a portion of bear management zone B, (2) different methods were used to arrive at the two population estimates, and (3) a higher human population exists in the MCSA (weighing against bear population density [Kohn, pers. comm.]) than in northwest Wisconsin.

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