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Nature, society and history in two contrasting landscapes in Wisconsin, USA
Interactions between lakes and humans during the twentieth century

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Abstract

Landscapes result from the interaction between nature and society. To understand current landscapes, it is essential to disentangle this interaction; to accomplish this, an historical approach is necessary. Here we focus on the interaction between humans and lakes during the last century in two sites in Wisconsin, USA, a state where lakes, in excess of 10,000, have played an important role in the evolution of the landscapes they belong to. We draw contrasts between the two localities, which are set in landscapes that differ in their physiographic setting, environmental history, and current structure. One, in northern Wisconsin, is a forested recreational lake district; the other, in southern Wisconsin, is dominated by agricultural uses and urban and suburban development. We contend that a common development in both localities has been the increase in the value that society attaches to lakes. As a consequence, lakes are playing a bigger role in the evolution of the terrestrial landscapes surrounding them.

Keywords: Lakes; Landscape; Environmental history; Humans; Settlement; Wisconsin; Land use/cover change; LTER

Introduction

Landscapes are cultural constructs just as they are natural constructs (Forman and Godron, 1986). Societies have interacted throughout history with the landscapes they inhabit or use. Insofar as societies have shaped landscapes, landscapes also have shaped societies. The outcome of this interplay at each point in history generally leaves an imprint, a legacy that influences to varying degrees the evolution of both landscapes and societies. An integral understanding of today's landscapes, therefore, cannot be attained without reference to the interplay between nature, society, and history. Furthermore, we cannot envisage and guide the future development of our landscapes without an understanding of the legacies we have inherited and the ones we are putting in place.

Here we present an example of this interplay in two contrasting landscapes in Wisconsin, USA. We focus on one natural resource, lakes, and examine their interaction with humans since the period of European settlement. The two landscapes differ in their geophysical setting, their history, their current structure, and, presumably, their future development. One of the landscapes, in north central Wisconsin, is today a largely forested recreational district where lakes are one of the main attractions. It is a landscape that, despite profound changes during the last century, still evokes images of wilderness. The other landscape is centered around the Yahara chain of lakes in south central Wisconsin. It is an agricultural and urban/suburban landscape, the seat of the state capital, Madison. They represent two extremes in the spectrum of Wisconsin

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landscapes and so provide an informative contrast of the range of interactions that occur between lakes and society.

Having over 10,000 lakes, innumerable wetlands and streams, and two major rivers, Wisconsin's entire history has been shaped by aquatic systems, even when they played only a supporting role. Unlike natural resources that are exploited for a profit, such as minerals, forests, or fisheries, many of the ecosystem services and values (recreational, aesthetic) of aquatic ecosystems have rarely been accounted for in market terms, and often have not been recognized until societies were forced to pay to restore services that previously had been a given (Postel and Carpenter, 1997). In a state that bases a sizeable fraction of its economy on the recreational value of lakes, where tourism is increasing and where, in places, urban and suburban development may be supplanting agriculture, lakes are beginning to play a more central role in the evolution of the landscapes that surrounds them.

Our choice of landscapes for this study is not casual. They are significant with respect to ecological research in two related ways. First, they contain some of the first aquatic ecosystems to be studied in North America, which means there are limnological records available for research going back more than fifty years. Second, together they constitute one of the sites of the US Long Term Ecological Research (LTER) program, a network of research sites funded by the US National Science Foundation to investigate ecological phenomena occurring at long temporal and large spatial scales (Magnuson, 1990, Swanson and Sparks, 1990). Our site, the North Temperate Lakes (NTL), which has been part of the LTER network since 1980, has only recently begun to address landscape scale processes and to incorporate questions related to nature and society into its research agenda. An analysis of land cover change and lakes is a key component of this agenda. Not only do we recognize the importance of changes in land cover to an understanding of changes in lake ecosystems, but the importance that lakes have played, and will play in the future, in shaping the landscapes surrounding them.

In the following pages, we first provide a brief explanation of what motivates our interest in the historical interaction between lakes and humans, and in doing so we offer a commentary on the development of a research program that has for years focused on traditional ecology and is now embracing a more interdisciplinary agenda. We then proceed to summarize the major goals and expectations of our landscape change analysis. Next, we sketch the environmental history of each of our two research sites, and critically present research questions and results from previous and ongoing research. We finish by drawing contrasts between the two landscapes analyzed.

Land cover change and lakes

Development of the project

The US Long Term Ecological Research (LTER) Network is a collaborative effort aimed at facilitating ecological research at longer temporal scales and larger spatial scales than normally addressed in ecological studies (Callahan, 1984; Franklin et al., 1990; Magnuson, 1990; Swanson and Sparks, 1990). Established in 1980 and composed currently of 21 sites, the LTER network strives to promote and conduct collaborative and synthetic research in five core areas that strictly focus on biophysical patterns and processes. This does not mean that LTER researchers have ignored human impacts on the ecosystems they have studied, as these are often too evident. But they have tended to treat them as external disturbances or external drivers of ecosystem change. No structured or systematic approach has been in place across the network to promote the study of the interactions between society and nature. Slowly at first, but with increasing momentum, the network is coming to realize that social-economic drivers need to be incorporated into ecological research. Historical milestones were the creation of an agriculturally focused LTER site (Kellogg Biological Station, Michigan), in 1987; the augmentation of grants for two LTER sites with the specific goal of implementing social science research, in 1994; and the establishment of two new LTER sites focused on urban/suburban landscapes (Central Arizona-Phoenix, and Baltimore Ecosystem Study), in 1997.

The North Temperate Lakes LTER (NTL-LTER) site was established at the onset of the LTER program, and was one of the sites augmented in 1994 to integrate social science into its research agenda. The augmentation also expanded the spatial scale of research at our site. Traditionally centered on seven core lakes in North Central Wisconsin (Magnuson, Bowser and Kratz, 1984), research at the NTL-LTER has since expanded to encompass a landscape and regional perspective best described as long-term regional limnology (Magnuson and Kratz, 1999). As the spatial scale was expanded to include landscapes, the study of human–lake interactions became unavoidable. While maintaining a strong focus on biophysical patterns and processes in lakes, current research at our site explicitly addresses the interaction between humans and landscapes.

Two areas are the focus of NTL-LTER research today (Fig. 1): the Trout Lake Area, and the Madison Lakes Area. At both sites, research is conducted at nested spatial scales. The Trout Lake Area is located in Vilas County, North Central Wisconsin. The landscape is glacial, with abundant forest cover, wetlands and lakes, and the main land use today is recreational. The Madison Lakes Area is composed of four core lakes. The

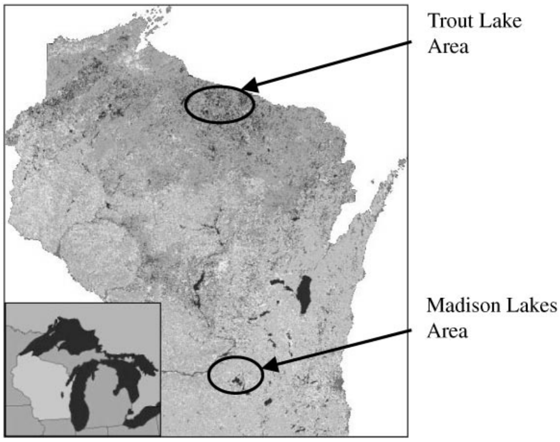

Fig. 1. Location of the two study areas in Wisconsin, USA.

landscape of interest includes the lakes' catchment areas, which are mostly agricultural and urban.

Each area has distinct environmental histories and inherited legacies. Because the relation between the physical setting and the socio-economic environment are peculiar to each site, lake influences on society, social and individual behaviors and attitudes toward lakes, and the impact of human activities on lakes also differ. Accordingly, the main goal of the social science program of the NTL-LTER site is to understand the way human, hydrologic, and biogeochemical processes interact within the terrestrial landscape to affect lakes and the way lakes, in turn, influence these interactions. A key objective is to develop a comprehensive history of settlement, land use and land cover around the Madison lakes and in the Trout Lake Area.

Land cover change and lakes: a research program

We are examining the interactions between lakes, their landscapes, and humans over the 20th century in our two study sites by asking three major research questions:

(1) *How have human uses of the lakes and the landscape affected lake ecosystems? In particular, how have changes in land use and land cover impacted lakes?*

In responding to this question, we recognize the need to work at two scales: the scale of lake watersheds, and the scale of riparian areas (the strip of land around the lake shore and along each side of contributing streams). While the amount, configuration and location of land use/land cover patches are important at both scales, small changes within the riparian areas may have disproportionate effects on land–water interactions because riparian areas often act as buffers that effectively filter materials transported from the terrestrial landscape to the aquatic ecosystems. Alternatively, they can act as a source of transported materials that have disproportionate effects because of their proximity to the aquatic ecosystems.

To address this first question, we take advantage of the long history of limnological research at both our sites, which were first studied by Birge, Juday and collaborators at the beginning of the century (Beckel, 1987). Birge arrived in Madison to establish the first academic limnology program in the United States in the 1880 s, and other researchers and agencies have studied these lakes over the years. Lake Mendota has been called "the most studied lake in the world", a statement that may well be true, judging by the two books (Brock, 1985; Kitchell, 1992) and thousands of scientific papers that deal with its ecology and management. Furthermore, Birge, Juday and collaborators sampled over 500 lakes in the Northern Highland Lake District, where our northern site is located, between 1929 and 1941. Other regional surveys covered the area in the fifties, seventies, and eighties, when the NTL-LTER was established. This wealth of limnological knowledge is invaluable for our study.

(2) *How have lakes affected human activities and patterns of human settlement in their vicinity?*

Rivers and lakes have often been preferred sites for human settlement because of the transportation, energy-generation, or recreational opportunities they afforded. Wisconsin's capital, Madison, lies on the isthmus between two lakes, Lake Mendota and Lake Monona. Lakes in the northern site are the principal attractor of tourists. In both cases, lakes have shaped the pattern of human settlement. We study this relation between lakes and people both diachronically and synchronically through analyses of current settlement patterns in relation to lakes, historical evolution of settlement, and by documenting the history of tourism.

(3) *How can we model the evolution of land cover change in northern and southern Wisconsin?*

We address this question through the construction of models of land use/land cover change. The value of the models is fundamentally heuristic – they help to discern which drivers have been important in determining changes in the northern and southern landscapes, they facilitate communication among scientists of diverse disciplines, and suggest new questions and new directions for research. Eventually, models will also be used to explore future land use/land cover under different planning scenarios. In all cases, the focus is on land cover change as it affects aquatic ecosystems, and on feedbacks between lake status and land cover change through social agents. For example, people's perceptions of the water quality of Lake Mendota may instigate changes in legislation and land use practices designed to improve water quality.

To address the questions summarized above, we are reconstructing land use/land cover in selected subwatersheds of the Madison Lakes Area, and selected watersheds and lakes within the Trout Lake Area in Vilas County. Our land use/land cover classification is performed at two different scales, characterized by the size of their minimum mapping unit: 160 m^2 for watersheds, and a finer resolution of 40 m^2 within riparian zones (30 m buffer from the lakeshore or on each side of streams). Land use/land cover is classified based on aerial photography dating back to 1937 (the year of the first statewide aerial survey of Wisconsin) at scales larger than 1 : 35,000. Classification is performed on geometrically corrected digital orthophotos. Extreme care has been taken in the production on these orthophotos from historical photographs to ensure the highest geometric quality and categorical accuracy of the resulting database. This is especially important regarding land use/land cover changes in riparian zones. Furthermore, due recognition is paid to the hydrologic characteristics of each of the landscapes; for instance, lakes in the glaciated northern landscape are often groundwater dominated, whereas in the Madison lakes, agricultural runoff and urban storm sewer systems need to be accounted for.

Environmental histories

The construction of a land use/land cover change database is a necessary step towards answering questions related to lake–human interactions, but is not sufficient for addressing the questions which arise in the course of this research. In this section we sketch the environmental histories of our two study landscapes focusing on human–lake interactions. Understanding the environmental histories of the sites helps to account for the legacies inherited from uses of the land and lakes in the past. This is particularly important regarding the years before aerial photography was available (1937 for the Madison lakes, 1938 for the northern lakes), for which a detailed reconstruction of land cover is not possible. As we will see, some land uses were established early, quickly, and with lasting effects.

Vilas County

Although we chose to focus on Vilas County, in north-central Wisconsin, our discussion would be easily transferable to neighboring counties and is representative of the Northern Highland Lake District and, perhaps, of other lake districts in the Great Lakes Region. This is a landscape dominated by the legacy of the Wisconsin glaciation. Large blocks of ice detached from the receding glaciers melted to form numerous lakes embedded in a matrix about 30 m thick of glacial outwash that overlies a Precambrian granitic bedrock. Seen from above, the landscape appears as a mosaic of mixed forest and extensive wetlands peppered by lakes. Indeed, water is the most prominent landscape feature (Fig. 2).

Northern Wisconsin has been populated for over 10,000 years. The first Paleo-Indians arrived as the glaciers were receding, no doubt attracted to some extent by the resources available from lakes, streams and wetlands. Other groups followed over the centuries, largely nomadic hunters and gatherers who relied on the lakes and streams for fish, wild rice, construction materials, and other resources. They also used fire to maintain openings in the forest which made travel easier and provided ideal habitat for many types of game (Nesbit and Thompson, 1989).

At the time that European settlers arrived, the area was populated by the Ojibway (Chippewa). Their encounter led to dramatic changes in the way of life of the indigenous people, principally through a new activity related to aquatic systems: the fur trade. We can only speculate as

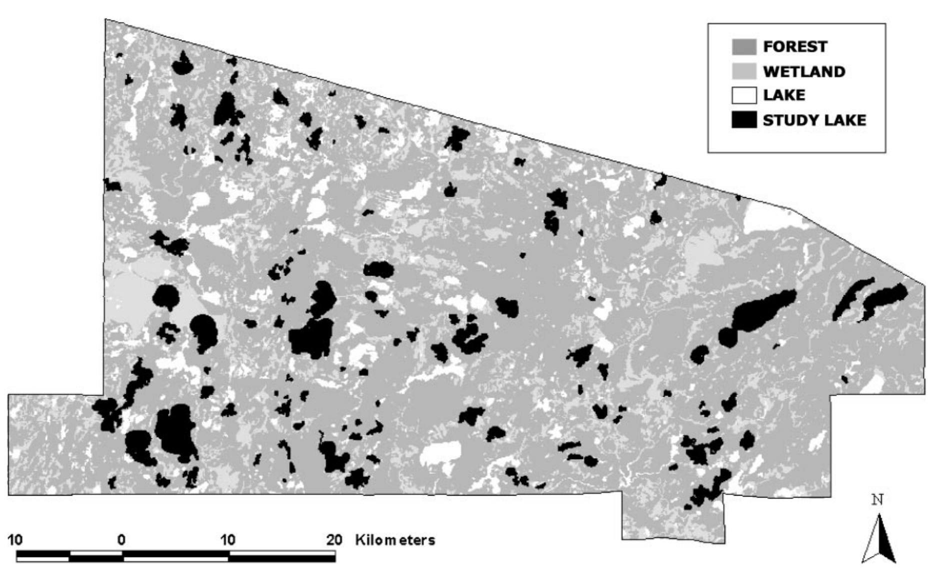

Fig. 2. Land cover in Vilas County.

to the impact the decimation of beaver populations had on the lakes and streams of Northern Wisconsin (and elsewhere in North America), but recent studies suggest that beavers are key shapers of landscapes, affecting hydrology, nutrient transport and accumulation, riparian vegetation and lowland forests (Naiman et al., 1986; Pollock et al., 1995).

The cession of Indian territories to the United States occurred principally through the *Treaty with the Chippewa* of 1842. In preparation for settlement, the area was surveyed by the General Land Office in 1864. Designed to assess the suitability of the land for agriculture and timber harvest, this survey also set the boundaries necessary for a market in land. The stage was set for the intense exploitation of the most valuable natural resource of the region: its forests. Fueled by avid markets for timber products in the growing economies of Midwestern cities and by the demand deriving from the colonization of the treeless Midwestern prairies (Cronon, 1991), Northern Wisconsin forests were felled in a period of half a century, from the 1870 s to the early 1920s. Lakes and rivers played a prominent role early on, as they provided transportation for the harvested logs to mills. Trees were felled during the winter, and the logs stored and sorted on iced-covered sloughs, lakes, and "flowages" (dammed river stretches). Riding on the peak flow of rivers during spring melt, logs were floated to the nearest mills and markets (Bawden, 1997; Fries, 1989).

The arrival of railroads in the 1870s profoundly impacted the timber industry, as they allowed year-round lumbering and access to more remote areas (Williams, 1989). Between 1899 and 1905, Wisconsin led the nation in timber production. Afterwards, with the most profitable forests, the white pine forests, approaching exhaustion, the production of hardwoods (hemlock and cedar) provided temporary relief to the lumbermen. By 1906, the lumber industry was in crisis. The intensive exploitation of forests left behind a desolate landscape, the "cutover", covered by huge tree stumps and slash, and ravaged by uncontrolled wildfires. It also left behind a territory with a transportation infrastructure in place, and large holdings of private land in the hands of land investors and railway companies seeking ways to capitalize on their investments. They settled on agriculture. The plough had successfully followed the axe in many other places. Why not in Northern Wisconsin?

The answer, though obvious to anyone today, seemed to elude the promoters of agriculture in the Northwoods at the time (Bawden, 1997; Clark, 1956; Helgeson, 1962). To encourage agricultural settlement, pamphlets were sent as far as Central Europe to attract colonists to the area, and the College of Agriculture of the University of Wisconsin was recruited to research and disseminate information on the agricultural potential of the region (Henry, 1896) – to no avail. With acidic or sandy, nutrient-poor soils, the shortest growing season in the state, and the added difficulty of clearing the land of stumps and boulders, agriculture was doomed to fail. By 1910, only 3% of Vilas County was under cultivation. With the failure of agriculture came land abandonment and tax delinquency. It soon became clear that the future of the region rested on reverting lands to forest, and in promoting the recreational values of the county.

Changes in legislation and associated changes in land tenure enabled the transition from agriculture to reforestation and recreation (Bawden, 1997; Jorgensen et al., in prep.; Wilson, 1958). In 1929, counties were accorded the possibility of raising timber with a taxation scheme that allowed for long-term investment. In 1933 Oneida County, just south of Vilas County, became the first county in the nation to adopt a rural zoning ordinance. Vilas County adopted its own only a few months later. The adoption of rural zoning and the differential taxation scheme for forest lands allowed the state to begin acquiring and developing lands for state forests, and they are largely responsible for the land tenure structure of the county today, with its large share of lands in public ownership (Fig. 3).

The original Vilas County zoning ordinance used only three categories: forestry, recreation, and unrestricted use. The drafters of the legislation recognized the importance of what would become the major economic activity of the county, and the one activity that defines its character today: tourism. Early in the century, Vilas County already attracted urbanites from Chicago, Milwaukee and Madison in search of the tranquillity that this land offered. Pamphlets and posters of the time actively promoted its many recreational opportunities, including boating, canoeing, and fishing (Schnaiberg, 2000). "Cottaging" also dates from this period – the construction of commercial tourist resorts and cabins, or small houses, generally used as second residences, mostly around lakes. The trend towards a more tourism-focused economy and lakeshore development increased over the century, especially after the economic bounty of the post-war period of the 1950s, and the resurgence of rural growth in the 1970s (Voss and Fuguitt, 1979). The number of new houses built during the 1960s was on average only 41 housing units per year (HU/yr); this figure increased to 857 HU/yr during the 1970s, decreased to 184 HU/yr during the 1980s, and increased again during the nineties, to 325 HU/yr (Anderson, 1996; Paul Voss, personal communication). Today there are nearly 33,000 buildings in Vilas Co.; half of them are located within 100 m of a lake's shoreline.

It is obvious, then, that lakes have strongly influenced patterns of human settlement. But exactly what characteristics of lakes attract development? We started to address this question by analyzing correlations between building density around lakeshores and lake characteristics (Schnaiberg et al., submitted). Our analysis

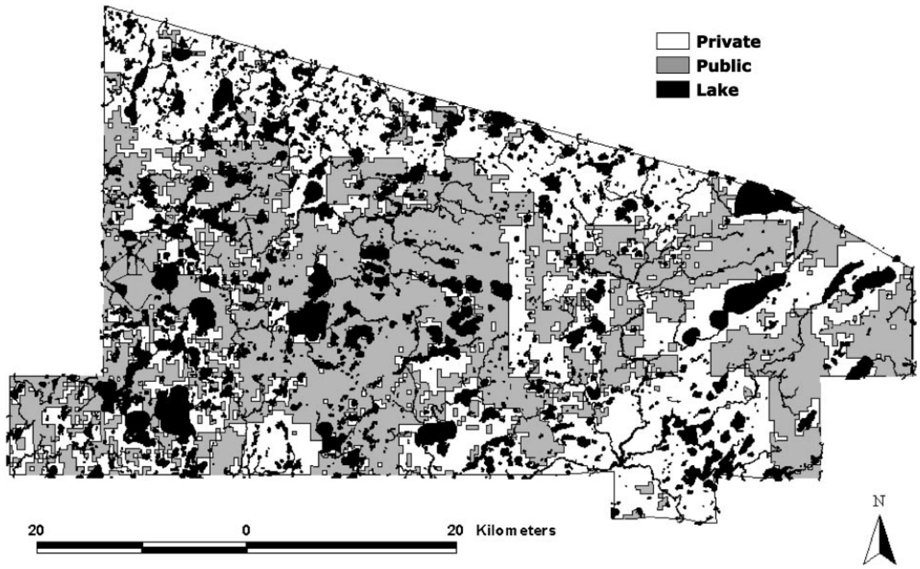

Fig. 3. Land ownership in Vilas County.

included 11 independent variables (in-lake characteristics, lake morphometry, lakeshore land cover, percent public ownership, and travel cost from the two major highways). Multiple regression models explained about 35% of the variability in building density, which was related to lake size, shoreline land cover (forest vs. wetland), and travel cost. Surprisingly, no in-lake characteristic (except water color, and only marginally), was related to building density. Such analyses are inherently limited. For example, social-economic dynamics are not accounted for, nor are the variety of idiosyncratic events that served to open up a specific lake for development at a specific point in time. The absence of a temporal perspective is particularly troubling (attractors of human settlement likely have varied over the years), and we are seeking ways of rectifying this shortcoming. A historical reconstruction from 1937 will help disentangle some of the hidden variability in building density among lakes, while other researchers in our program are focusing on people's attitudes towards lakes in an attempt to explain what moves people who settle near a lake.

What has been the impact of human activities on lakes over the last 150 years? One would think that the large disturbances occasioned by the harvest of timber over large tracts of land and the wildfires that followed should have heavily impacted lakes. We do not have direct limnological measurements from before the logging period, so we have to rely on paleolimnological studies (the reconstruction of past lake characteristics based on algae and pigments, remnants of microscopic animals, and chemical species preserved in the sediments of lakes), and on the analysis of similar disturbances in similar lake districts today (Lathrop, 1994; Paterson et al., 1998). While these suggest that an increase in nutrients and ash occurred, perhaps with concomitant changes in lake production and in the optical qualities of water, the effects were neither strong nor lasting. The explanation for this may lie in the low nutrient pool stored in the forests, and in the peculiar hydrology of this region, dominated by groundwater, which dampens the intensity of land–water interactions.

Thanks to Birge, Juday, and collaborators, we have direct limnological data from the 1930 s (at least for water chemistry) that we can compare with recent data to answer the question of whether lakes have changed over the last 50 years, and whether that change is related to lakeshore development. Eilers et al. (1989) carefully analyzed changes in pH, conductivity (a measure of total dissolved solids), and alkalinity (a measure of a lake's buffering capacity against acidification). They found significant changes related to the degree of lakeshore development. In a broader analysis, we looked at relative changes in nine lake chemistry variables and gathered information on building number and density around lakes today and in the 1930s, road density, and lake and lake catchment characteristics. We found that changes in several of the variables were related to changes in lakeshore development, and in most cases this association could be at least partly attributed to road salting. Other variables (e.g., pH and alkalinity), despite documented increases over the last 50 years, appear unrelated to lakeshore development. Other processes, acting perhaps at a regional scale, apparently were responsible for these changes (e.g., changes in atmospheric deposition).

These changes in lake chemistry are at best modest, certainly small enough that lake users would not perceive them. But cottaging, and, more generally, other human activities, have impacted lakes in other ways that we cannot gauge directly because of the scarcity of historical data. We need to resort to comparisons of lakes that today have different degrees of lakeshore development (i.e., space-for-time substitution). From these, we can begin to document the kinds of changes associated with lakeshore development:

1. Direct changes to the riparian zone. Construction of cottages is generally accompanied by some degree of landscaping (clearing of trees and understory vegetation, introduction of ornamental species, lawn-growing), with effects on the composition, diversity, and buffering effectiveness of riparian vegetation, and indirect effects on the associated fauna (Wisconsin Department of Natural Resources, 1996).
2. Direct changes to the lake's littoral zone. Macrophytes (macroscopic plants that grow on the littoral zone of lakes) are impacted by lakeshore development, as is the amount of coarse woody debris (tree trunks and branches that naturally fall on the water), often removed from the water by lakefront owners. There are also indirect impacts on littoral fauna and even on pelagic (open water) fauna, since macrophyte beds and coarse woody debris provide habitat, feeding opportunities, or refuge for many species, including young-of-the-year of pelagic fish species (Christensen et al., 1996; Schindler et al., 2000).
3. Changes directly related to lake use. Besides direct impacts of lakeshore development, there are impacts of lake use by property owners and occasional tourists who stay at hotels, resorts, or campgrounds. Fishing, fish stocking, and the intentional or unintentional introduction of exotic species are among the most important of these impacts (Hrabik and Magnuson, 1999).

It is clear from this discussion, therefore, that documenting changes in lakeshore development will provide the best single measure of the intensity of human-lake interactions over the last 50 years.

Madison Lakes

If the conversion from forest to agriculture essentially by-passed northern Wisconsin (albeit in a complex way), south central Wisconsin is essentially a textbook example of the progression from wilderness to farms to towns and cities that is characterized by Frederick Jackson Turner's American frontier thesis. Before European settlement, the landscape around Lake Mendota was composed of prairie, oak savanna, and various types of woodlands; wetlands were abundant, riparian vegetation thrived along stream banks and lake shores; and the lakes had clear waters and healthy macrophyte beds. An early explorer described them as "the most beautiful bodies of water I ever saw" (Wakefield, 1834). The scenic beauty of the area undoubtedly contributed to the development of Madison on the isthmus between lakes Mendota and Monona. Unlike other towns built on transportation corridors or near natural resources, Madison was born out of the boom in land speculation in the 1830s, after conflict with the native population had been settled and the land was ready to welcome colonists (Hudson, 1997). The lakes continue to be an important asset of the community today.

Euro-American colonization started in the 1830s. Only four decades later, forests had been cleared, wetlands drained, and the amount of agricultural land had reached the proportion that has maintained until today (Fig. 4). Changes in the lakes followed closely changes in the landscape. Agricultural runoff soon increased the productivity of Lake Mendota; by the 1880s, nuisance blue-green cyanobacterial blooms were not uncommon, a sure sign of lake eutrophication. Lake eutrophication is caused by the increased loading of nutrients, particularly phosphorous, to the lake. This results in increased production which, in turn, provokes a host of changes in the lake that include lower transparency, unsightly algal blooms, and oxygen depletion of bottom waters. These changes decrease the recreational value of the lake, cause health concerns, and increase the cost of water use. Phosphorus loading to the lakes also increased as farmers switched from the cultivation of wheat to the cultivation of corn (which exposes soil to erosion for longer periods) and, especially, as farmers increased the application of fertilizers after World War II (Lathrop, 1992; Carpenter et al., in prep.). Exacerbating the problem, land cultivation also reduced the amount of riparian cover along contributing streams, and increased the load of soil and sediment to the lake, two processes that increase the transport of nutrients from the uplands to the lakes.

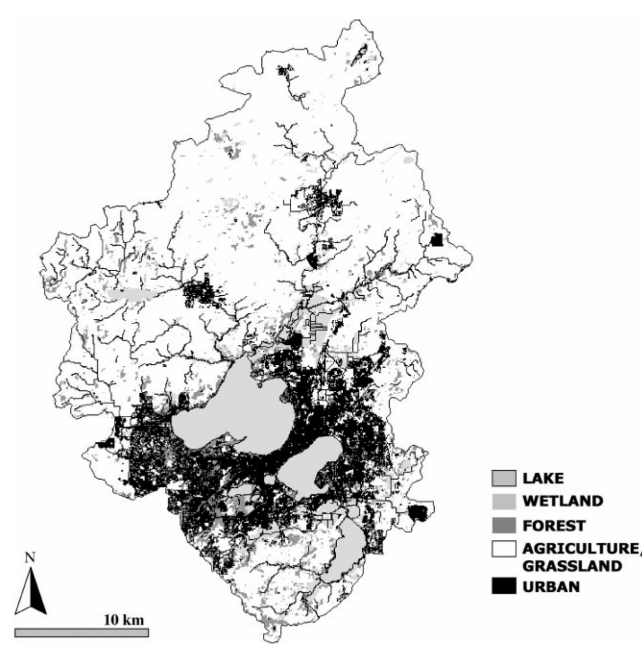

Fig. 4. Land cover in the Mendota lakes catchments.

Human activities affected land and lake properties in other ways. Wetland habitat has been lost to agriculture, urbanization, and other uses. In 1847, a dam was built at the outlet of Lake Mendota that raised the water level 1.5 m, flooding wetland and modifying the littoral zone. Lake Wingra was originally a wetland draining into Lake Monona that was converted into a shallow lake by water level manipulation in the early 1900s (Bauman et al., 1974). Littoral zone habitats in Madison lakes declined in area and diversity, the result of several interacting factors, including declines in water clarity, invasion by Eurasian milfoil (*Myriophyllum spicatum*), introduction of carp (*Cyprinus carpio*), and locally intensive aquatic weed management practices, such as harvesting or application of herbicides (Nichols and Lathrop, 1994). Degradation of littoral habitat has been followed by the extirpation of many small-bodied littoral zone fish species (Lyons, 1989), some of which may have been casualties of fish stocking with piscivores.

All these changes in lakes can be linked to either increased nutrient loads from agricultural or urban uses in the catchment, and to the shear increase in human population in the catchment, with attendant increases in the intensity of lake use. In short, changes in lakes are inextricably linked to changes in land use in the watershed. Water quality problems have been recognized since at least the 1940s (Hasler, 1947), and efforts directed at lake restoration are just as old.

Controlling nonpoint pollution (pollution from diffuse sources, such as from fertilizers and animal manure) is difficult and expensive (Novotny and Olem, 1994). Thus, lake restoration relies first on controlling point-source pollution and on managing the lake itself to mitigate the impact of increasing loads of phosphorous. Point sources of phosphorus (from sewage discharge) became significant in the 1950s and 1960s. Madison's sewage had been discharged downstream of Lake Mendota since the early 1900s (creating water quality problems in Lake Monona), but sewage effluents from the growing communities north of the lake continued to be discharged into Lake Mendota. As concern over the deteriorating water quality of Lake Mendota grew, point sources were targeted. By 1971, all sewage effluents had been diverted, but the reduction in phosphorus load (around 30%, Lathrop, 1990) proved insufficient to curb eutrophication. In-lake management in a lake the size of Mendota ($40\,km^2$) is of limited use. Biomanipulation was attempted, a management practice that involved stocking the lake with piscivorous fish with the expectation that they would lower the pressure that planktivorous fish exert on their food base, zooplankton. If zooplankton are allowed to increase, they can keep algal biomass down, increasing water transparency and generally mitigating the symptoms of eutrophication. Unfortunately, massive stocking with piscivorous fish attracted large numbers of the true top predator of the lake – anglers. The increase in angling effort diminished the impact of the biomanipulation effort, a lesson about the importance of human–lake interactions learned the hard way (Kitchell and Carpenter, 1993).

By the mid-1990s, it was clear that restoring lake Mendota would involve the aggressive implementation of nonpoint pollution control measures, an effort that became a political reality with the designation of the Lake Mendota Priority Watershed Project, a project managed by the Wisconsin Department of Natural Resources, the Land Conservation Department and Lakes and Watershed Commission of Dane County, and others (Carpenter et al., in prep.). The NTL-LTER project contributes to this effort with scientific expertise and ongoing research projects regarding phosphorus in the watershed (Soranno et al., 1996; Bennett et al., 1999), farm practices related to nonpoint pollution (Nowak, 1987), and the economic value of aquatic ecosystem services (Carpenter et al., 1998; Wilson and Carpenter, 1999). From a scientific point of view, the Lake Mendota Priority Watershed Project constitutes an unprecedented large-scale, long-term experiment (Carpenter et al., in prep.). By attacking the root of the problem (land use in the watershed) the project takes a radical approach to solve the problem of eutrophication in Lake Mendota. In doing so, it has to deal with the changing social context of the lake, as well as with the legacies of past land use and lake management.

The social context of the Lake Mendota watershed is changing. Dane County, where Madison, the Madison lakes, and most of their catchments lie, is one of the fastest growing counties in the Midwest, with an average annual population increase of about 1.4% since 1990, and a projected growth of 22.7% from 1996 to 2020. Most of that growth is expected in villages and small cities in the suburban fringe surrounding Madison, and it will occur often at the expense of agricultural uses. One state official described the efforts to preserve farmland as "a battle of plats versus plows" (cited in Paulson, 1997). As the suburban population of Dane County increases, the share of nonpoint pollution originating in runoff from impervious surfaces and suburban lawns will increase. Most importantly, phosphorus export is higher during construction due to increased erosion rates of exposed soil. This is particularly true when development occurs on former agricultural land, where the amount of phosphorus stored in the soil is substantially augmented, a legacy of past land use. Concentrations of phosphorus in the agricultural soils of Lake Mendota's watershed have been building up by as much as 575×10^3 kg per year since at least the 1970s (Bennett et al., 1999). Nonpoint nutrient management in lake Mendota is chasing a moving target.

Towards a synthesis

Our analyses focus on the interactions between humans and lakes on two lake landscapes as different as can

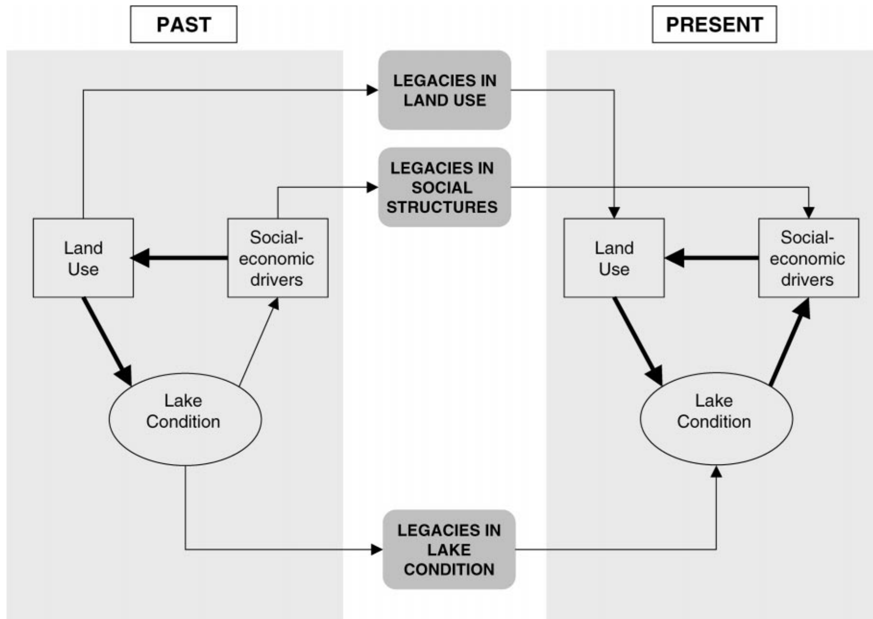

Fig. 5. Diagrammatic representation of interactions between land use and lakes during the 20th century.

be found in Wisconsin – different in their physiographic setting, their history, and their current status. Although a difficult task, we believe it is possible to find a common theme informing their histories and future development. Here we attempt to summarize the key components of a possible synthesis (Fig. 5).

Although the environmental histories of each of the landscapes analyzed differs considerably, they share several characteristics. Human settlement did not occur randomly, but rather settlement near lakes was favored even if lakes were not what initially attracted settlers. People were drawn to these areas because there was a natural resource that could be profitably exploited, whether forests or agricultural land. Although direct exploitation of lakes was marginal, lakes were impacted by land uses in the landscape. However, feedbacks from lakes to humans and, through society, to land use and land cover, were initially weak, if they existed at all.

A crucial development during the 20th century that is common to both of the landscapes studied, and probably to many other lake districts, is that the value of services provided by lakes has been increasingly recognized and deemed important by society. It has become clear to society that changes in lakes are linked to uses of the land surrounding the lakes, and that, as a consequence, management of land uses is crucial for the preservation or restoration of desired lake services. In short, feedbacks from lakes to society and, through society, to land use and land cover have become prominent over the last fifty years.

The importance of these feedbacks can be gauged by analyzing attitudes and behaviors toward perceived lake quality, involvement in public policy, and willingness to pay for lake preservation or restoration (Jorgensen et al., in prep.; Wilson and Carpenter, 1999; Carpenter et al., in prep.). In Vilas County, for example, lake management organizations, formed by land owners around lakes, are instrumental in the ongoing process of lake classification by which lakes are categorized according to physical (e.g., size, morphometry), ecological (e.g., water quality, fisheries), and sociological (e.g. extent of lakeshore development) characteristics. Lake classifications will be used by local governments to target policies and land use regulations. Lake associations have succeeded also in getting the county government to re-zone privately owned shoreline to a more restrictive category.

As the population of Vilas County grows and lakeshore development reaches a point of saturation, and as the population of Madison and surrounding communities increase, the pressure of human activities on lakes will only increase. Whether this increased pressure can be counterbalanced by growing awareness and appreciation of lake services, and greater societal (and electoral!) interest in preserving or restoring these services depends on complex social-economic-ecological dynamics that will require novel tools to be explored (Carpenter et al., 1999). What is clear is that an understanding of human–lake interactions cannot be attained without due attention to land use, lake use, the social-economical factors that drive both, and historical legacies.

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