Restoration of Canvasback Migrational Staging Habitat in Wisconsin

A Research Plan With Implications For Shallow Lake Management

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Cover photo by Michael Haramis, U.S. Fish and Wildlife Service.

ABSTRACT

Throughout the 1900s degradation of staging habitat in the Upper Midwest, including several sites in the southeastern half of Wisconsin, led to large concentrations of migrating canvasbacks on limited habitat along the Upper Mississippi River (UMR) from the mid-1960s to the late 1980s. This reliance on just a few habitats left a major segment of the North American population of canvasbacks susceptible both to catastrophic events affecting the health of the birds and to the degradation of the last remaining quality habitats. Thus, the development of alternative staging habitats must be addressed if this segment of the North American population is to remain secure.

This report (1) assesses present status of canvasback staging populations and habitat in Wisconsin, (2) describes goals for management of canvasback staging populations and habitat, (3) outlines the research strategy necessary to formulate management plans for restoration of staging habitats in the southeastern half of Wisconsin, and (4) outlines an ecosystem approach to managing large, shallow lakes, which typify canvasback staging habitat. Information was compiled during 1985-90. Primary sources of information included a literature review, discussions with natural resource personnel from several agencies, a review of Wisconsin Department of Natural Resources (DNR) file data, and preliminary results of a DNR Bureau of Research study on the status of canvasback staging populations and habitats, which began in 1985.

Historical accounts indicated that Lakes Koshkonong and Puckaway attracted large numbers of migrating canvasbacks in the late 1800s and early 1900s. Census data indicated that Lakes Poygan, Winneconne, and Butte des Morts hosted peak fall populations ranging from 8,000 to 77,000 in the 1950s and early 1960s. Lake Mendota attracted 61,000 in 1954. These sites apparently fulfilled the critical habitat requirements of migrating canvasbacks: large littoral areas supporting an abundance of readily accessible foods, especially American wildcelery, sago pondweed, and macrobenthos, as well as large open-water areas providing refuge from disturbance.

Most canvasbacks stopped using these lakes after habitat quality declined due to nonpoint and point source pollution, high and fluctuating water levels, wave action, introduction of common carp and resulting unbalanced fish communities, and human disturbance. Although North America's eastern population of canvasbacks declined during the mid-1980s to levels below those occurring in the mid-1960s, staging populations using lakes in the southeastern half of Wisconsin declined much more precipitously. From the late 1960s to the mid-1980s, no site surveyed in the southeastern half of Wisconsin had peak fall populations greater than several hundred to several thousand. Peak weekly populations for 15 sites in the southeastern half of Wisconsin ranged from 160 to 2,198 in fall and 4,850 to 10,215 in spring, 1985-90. Lake Poygan typically attracted the most canvasbacks during this period. In contrast, Pools 7-8 of the UMR attracted peak fall populations exceeding 60,000 during 1973-84, and this trend continued into the late 1980s.

From 1979-84, canvasback use-days on Pools 7-9 of the UMR averaged about 2.5 million annually. In the southeastern half of Wisconsin, annual use-days for 15 sites averaged about 100,000 and ranged from 45,000 to 159,000 from 1986-89. Based on federal and state collaboration, a regional goal was proposed that called for redistributing about 50% of the use-days from Pools 7-9 to other staging habitats. Wisconsin DNR established the goal of providing for 625,000 use-days annually, distributed on at least 3 sites in the southeastern half of the state, by accommodating present use-days and redistributing about 20% of the annual use-days from the UMR Pools. Wisconsin's goal requires the provision of about 240 ha of wildcelery, 180 ha of sago pondweed, or 1,815 ha of macrobenthos beds on each of the 3 sites. Furthermore, management strategies should address boating disturbance where necessary through lake-use restrictions. Sites apparently having the greatest potential for management and restoration include Lakes Poygan, Winneconne, Butte des Morts, Koshkonong, Puckaway, and Beaver Dam. Of these sites, only Lake Poygan, with 355 ha of wildcelery, presently provides more than 10-20 ha of relatively dense wildcelery or sago pondweed. Limited data and circumstantial evidence suggests that Lakes Poygan, Winneconne, and Butte des Morts support relatively low populations of the macrobenthos species important to canvasbacks, while Lakes Koshkonong and Beaver Dam may support moderate to high densities of macrobenthos.

Due to inadequate baseline data and uncertainty about the source of factors contributing to habitat degradation on these sites, specific management plans cannot be developed without additional research. The proposed research strategy includes acquiring data on present status of canvasback populations and habitat quality; determining limiting factors (and their sources) for aquatic macrophytes, macrobenthos, and disturbance; and evaluating restoration techniques for each of 6 study sites. Most of the suggested factors limiting the abundance of submerged macrophytes and macrobenthos have system-wide and often watershed-wide causes that also affect fish, other wildlife, and water resources. Therefore, restoration and management of staging habitats require an ecosystem approach that considers management goals for fish, wildlife, and water resources. Many of these limiting factors and their management strategies are outlined in an appendix on shallow lake management. The information presented in this report should be useful to managers in formulating plans for managing canvasbacks as well as any other species associated with shallow lake ecosystems.

An addendum briefly describes a significant decline of wildcelery and macrobenthos that occurred in most pools of the UMR in 1988-89 after this report was prepared. This decline reinforces the need for Wisconsin to quickly achieve the goals for restoration of staging habitat and to expand the goals and restoration strategy to include the UMR.

Key Words: *Aythya valisineria,* staging habitat, food resources, disturbance, habitat restoration, shallow lake management, Lake Poygan, Lake Winneconne, Lake Butte des Morts, Lake Koshkonong, Lake Puckaway, Beaver Dam Lake.

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by Rich Kahl

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INTRODUCTION

Canvasback ducks[1] are threatened by loss and degradation of breeding, migrational, and wintering habitats throughout North America (North. Prairie Wildl. Res. Cent. 1982, Serie et al. 1983, U.S. Fish and Wildl. Serv. 1984). In recent years, relatively low canvasback populations have led to hunting season closures and considerable concern among waterfowl biologists and hunters. The U.S. Fish and Wildlife Service (FWS) has identified the canvasback as a priority species for increased research and management due to staging habitat loss and to hunter demand exceeding resource supply (North. Prairie Wildl. Res. Cent. 1982, U.S. Fish and Wildl. Serv. 1984). A 1982 issue paper by the Northern Prairie Wildlife Research Center, "A Critical FWS Need: Management Strategy for Evaluating and Rehabilitating Canvasback Migration Habitat in the Great Lakes Region," emphasized the significance of staging habitat loss and the need for habitat restoration founded on a solid research program.

Large, shallow lakes and river pools offering abundant food resources and refuge from disturbance provide optimal staging habitat for canvasbacks (Stoudt 1960). Historically important sites in Wisconsin lie southeast of a line roughly from Marinette through Wautoma to Madison. From the 1920s through the 1960s, deterioration of staging habitat in this southeastern half of Wisconsin (Zimmerman 1953; Thompson 1959; Jahn and Hunt 1964; Wis. Dep. Nat. Resour. 1969; Harris et al. 1982; Kahl, in press *a*) and elsewhere in the Upper Midwest (Mills et al. 1966, Trauger and Serie 1974, Martz et al. 1976) altered canvasback migration patterns. These changes led to large congregations of canvasbacks on limited habitat along the Upper Mississippi River (UMR) during the last 3 decades (Serie et al. 1983). This reliance by a major segment of the population on a restricted habitat base results in susceptibility to catastrophic events and a lack of alternative habitats in the event of habitat degradation on the UMR (U.S. Fish and Wildl. Serv. 1984).[2] Thus restoration of canvasback staging habitat is critically needed in southeastern Wisconsin.

In 1984 the Bureaus of Research and Wildlife Management and the Lake Michigan District of the Wisconsin Department of Natural Resources (DNR) took the initiative in habitat restoration efforts by cooperatively developing and implementing a research project: "Canvasback Status and Habitat Management" (Wis. Dep. Nat. Resour. 1984). The primary objectives of this project are to: (1) develop a research/management plan that summarizes existing data on canvasbacks and sets forth goals and strategies for restoring habitat and (2) carry out the strategy through joint effort of the Bureau of Research and various management bureaus. The research project proposal and design recognized that large, shallow lakes are complex aquatic ecosystems and that management goals for the fish, wildlife, and water resources of these ecosystems would overlap and intertwine. Therefore, success in managing canvasback staging habitat was linked to effectively managing large, shallow lakes through an ecosystem approach.

To promote an ecosystem approach to shallow lake research and management, the DNR Bureau of Research sponsored a 1985 workshop, "Management of Shallow-water Lakes for Wildlife, Fish, and Water Resources." Workshop participants concluded that "(1) large, shallow lakes require special management attention because they provide critical habitat for many unique wildlife, fish, and plant species, and (2) the complexity of factors associated with managing large, shallow lakes requires a multidisciplinary approach" (K. Klepinger, Wis. Dep. Nat. Resour., to J. Huntoon, in letter 13 December 1985). Also in 1985, the DNR Lake Michigan District and Bureau of Research collaboratively proposed an ecosystem approach to managing the most significant shallow lake resource in Wisconsin—the Winnebago Pool Lakes—which had provided exceptional staging habitat for canvasbacks in the 1950s and early 1960s (Jahn and Hunt 1964; G. Jolin and J. Dunn, Wis. Dep. Nat. Resour., unpubl. data). A comprehensive management plan for the Winnebago System was subsequently developed, and implementation was initiated in 1989-90 (Wis. Dep. Nat. Resour. 1989*a*).

This Technical Bulletin satisfies the first objective of the canvasback research project by outlining a research plan for restoration of canvasback staging habitat for the southeastern half of Wisconsin and an ecosystem approach to managing large, shallow lakes. This report describes: (1) North American canvasback populations and canvasback migrational staging populations and habitat in southeastern Wisconsin, (2) critical components of staging habitat, (3) daily energy requirements of migrating canvasbacks, (4) management goals for canvasback staging populations in southeastern Wisconsin, and (5) the proposed research strategy and description of study sites for restoration of canvasback staging habitat. An appendix presents detailed information on shallow lake management problems, goals, and strategies. This is intended to be a dynamic document, to be revised as better information becomes available and as canvasback populations and staging habitat conditions change.

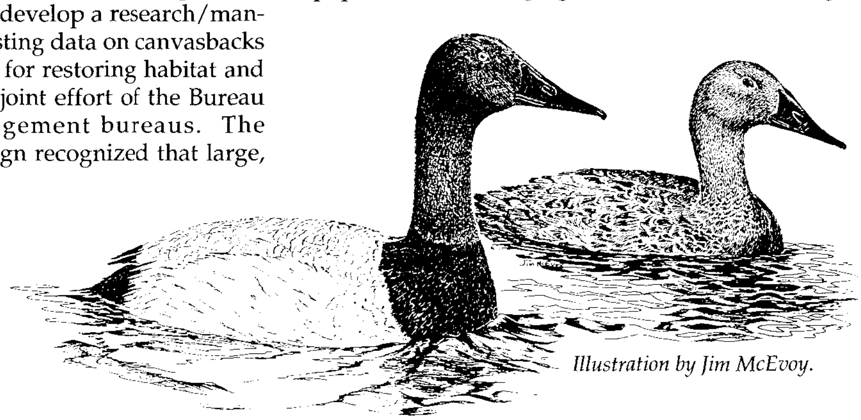


Illustration by Jim McEvoy.

[1] Scientific names of species mentioned in this report are provided in Appendix B.

[2] Since this report was prepared, a significant decline of wildcelery and macrobenthos occurred in most pools of the UMR in 1988-89. These events reinforce the need for Wisconsin to quickly achieve management goals for restoration of staging habitat for canvasbacks and to expand the goals and restoration strategy to include the UMR (see Addendum for further discussion).

METHODS

Information and data presented in this report were gathered during 1985-90 and were derived from a literature review, interagency discussions (especially with DNR, FWS, and University of Wisconsin personnel), a review of DNR file data, and a Bureau of Research study initiated in 1985 on the status of staging canvasback populations and habitats in the southeastern half of Wisconsin.

Historical information on canvasback staging populations dating from the late 1800s was derived from a literature review and DNR file data. Data on populations in southeastern Wisconsin since 1985 were acquired through aerial surveys conducted for the Bureau of Research study. These surveys involved 3-4 weekly censuses of 15 sites from mid- to late-March through mid-April and from mid-October through mid-November each year.

Critical components of staging habitat were assessed through a literature review and interagency discussions. Information on the refuging requirements was also derived from the Bureau of Research study that investigated disturbance to canvasbacks on Lake Poygan during 1986-87 (Kahl, in press *b*).

Management goals for canvasback staging populations and habitat were derived from a literature review, interagency discussions, summary of canvasback census data from 1985-89, and a synthesis of published information on energy requirements and food resource availability and utilization by canvasbacks and lesser scaup during staging and migration. Canvasback use-days for 1985-89 were estimated from the average of counts of consecutive censuses multiplied by the number of days between censuses.

The research strategy and information needs were determined through literature review, interagency discussions, review of DNR file data, and an informal survey of DNR resource managers conducted in 1985. The primary objective of the survey was to determine the availability of baseline data from wildlife, fish, and water resource managers responsible for managing 26 lakes initially selected as potential study sites in the southeastern two thirds of Wisconsin. A general research strategy was outlined in a project document for the Bureau of Research canvasback study (Wis. Dep. Nat. Resour. 1984). The strategy presented in this plan refines and elaborates on the general strategy of the project document.

Selection and description of study sites was accomplished through the manager survey, literature review, review of DNR file data, and the Bureau of Research study. Due to a paucity of data on habitat quality for most prospective study sites, the Bureau of Research canvasback study initially focused on acquiring baseline data (especially food resource availability and water quality) for the most promising sites. For these preliminary study sites, the abundance and species composition of submerged macrophyte beds were determined through color aerial photography and rake sampling (Jessen and Lound 1962) along transects through these beds during 1986-89. Water clarity was monitored biweekly from mid-April through late August at 3 mid-lake locations. Contribution of waves to turbidity through resuspension of sediments was assessed by comparing surface wind speeds to water clarity for each sampling date.

Information on factors contributing to declining fish and wildlife habitat quality, their sources and effects, and management strategies for mitigating these problems associated with large, shallow lakes was derived from literature review. Projected costs for the various management strategies are not included for a variety of reasons: literature on these strategies often did not report costs, costs and effectiveness varied considerably among projects, costs were outdated, or costs were not directly applicable to large, shallow lakes, since most other projects have targeted smaller and often deeper lakes.

The main body of this document cites supporting references in the text. For Appendix A, supporting references are provided in a bibliography to accommodate the nontechnical format.

STATUS OF CANVASBACK POPULATIONS

North American Populations

Canvasback breeding populations occur in North America from the north-central U.S. through central Canada to Alaska. Primary breeding grounds are located in the northern prairie pothole and southern parkland regions of west-central Canada. The continental population consists of 2 distinct subpopulations, divided according to breeding and wintering areas (Fig. 1) (Bellrose 1978). The western population breeds along the western edge of the breeding range, north to Alaska, and winters along the west coast of North America. The eastern population (EP) breeds throughout the north-central U.S. and west-central Canada and winters primarily along the east- and Gulf-coast areas of the U.S.

The North American breeding population has apparently fluctuated considerably since 1955 (Bartonek 1990) (Fig. 2). Relatively low populations during the early 1960s and early 1970s resulted in strictly limited or closed hunting seasons; these protective measures, coupled with major increases in number of wetlands on the breeding grounds in subsequent years, apparently produced a rapid increase in canvasback populations (U.S. Fish and Wildl. Serv. 1984). However, season closures in 1986-89 did not produce a similarly rapid response by canvasback populations (Bartonek 1990), probably because of severe drought on the breeding grounds, continued habitat loss and degradation, and illegal-hunting mortality, especially of hens. Populations approximated 505,000 during 1988-90 (3-year annual average) (Bartonek 1990). During the same period, the EP comprised about 62% of the North American population and approximated 311,000 (Bartonek 1990).

Present FWS goals for the North American and EP breeding populations are 580,000 and 420,000 (72% of the North American population), respectively (U.S. Fish and Wildl. Serv. and Can. Wildl. Serv. 1986). The FWS has also set 500,000 and 360,000 as a critical level (3-year average) for the North American and EP breeding populations, below which the FWS considers hunting season closures (Bartonek 1990). Eastern breeding populations below this level since 1986 (Bartonek 1990) have resulted in restricted or closed

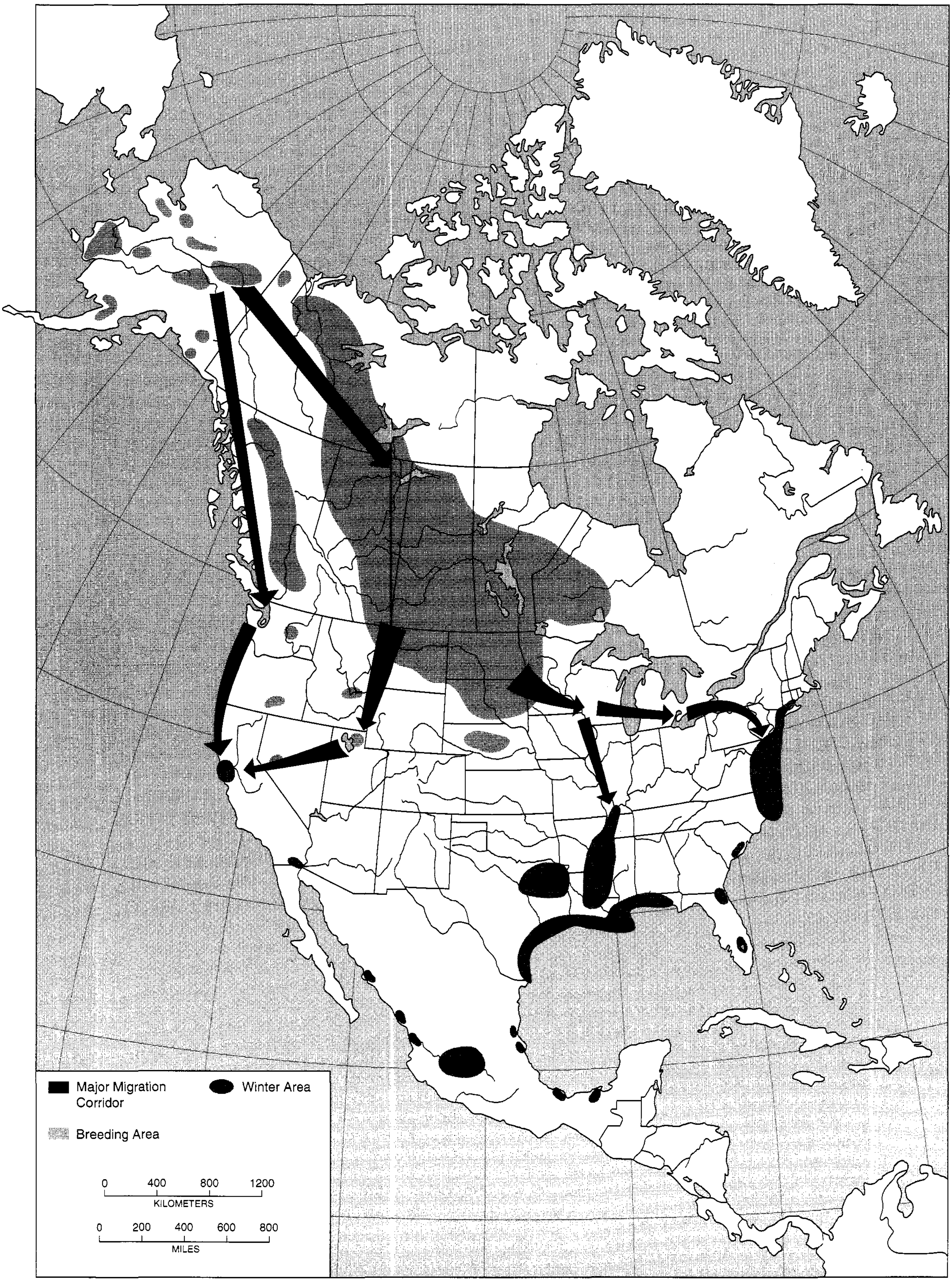


Figure 1. *Breeding, migration, and wintering distribution of canvasbacks in North America (adapted from Bellrose 1978, Serie et al. 1983, and U.S. Fish and Wildl. Serv. 1984).*

seasons from 1986-90. To achieve these goals and provide further hunting opportunity requires the reduction of mammalian predation during nesting; the improvement of important breeding, migration/staging, and wintering habitats; and the protection of females during hunting seasons (U.S. Fish and Wildl. Serv. 1984).

Eastern Population During Migration

Upper Midwest Populations

Major migration routes through the Midwest have generally remained intact during the 1900s, but habitat loss and degradation have redistributed staging, migrating, and wintering populations along these routes (Serie et al. 1983) (Fig. 1). Redistribution during migration has been from a broad temporal and spatial pattern in western Minnesota, southeastern Wisconsin, central Illinois, and eastern Michigan to a few pools along the UMR (Serie et al. 1983). Canvasbacks apparently responded to proliferation of American wildcelery on the UMR, as well as habitat deterioration on other sites. Major segments of the EP canvasbacks staged on or migrated through the complex of Pools 7-9 and Pool 19 of the UMR during the 1970s through the mid-1980s, and in some years over 50% of the winter inventory estimate for the EP was concurrently present on Pools 7, 8, and 19 (Serie et al. 1983; C. Korschgen, U.S. Fish and Wildl. Serv., pers. comm.).

Wisconsin Populations

The major migratory corridor for the EP across Wisconsin extends from the UMR at LaCrosse through the southeastern part of the state to the eastern Great Lakes (Fig. 1) (Serie et al. 1983, U.S. Fish and Wildl. Serv. 1984). The portion of the EP that depends on this migratory route is the focus of this report.

The most important Wisconsin sites for migrating canvasbacks during the past century in Wisconsin were the UMR (Pools 7-9) (Serie et al. 1983) and shallow lakes or lakes with large littoral zones in the southeastern half of the state, including Lake Koshkonong; Lake Puckaway; Lakes Poygan, Winneconne, and Butte des Morts of the Winnebago Pool; Lake Mendota; and lower Green Bay (Jahn and Hunt 1964) (Fig. 3). Severe habitat degradation occurred on all of these sites except the UMR sites, due to various factors including high and fluctuating water levels, proliferation of undesirable fish (primarily carp, but also freshwater drum, bullheads, and other species that are destructive to habitat at high population densities), increased sedimentation and eutrophication, and wave action (Zimmerman 1953; Thompson 1959; Jahn and Hunt 1964; Wis. Dep. Nat. Resour. 1969; U.S. Fish and Wildl. Serv. 1979; Harris et al. 1982; Lathrop 1988, 1989; Kahl, in press *a*). The peak fall population for southeastern Wisconsin since 1947 was 88,000 in 1955; Lake Poygan contributed 57,000 to this total (Jahn and Hunt 1964; G. Jolin and J. Dunn, unpubl. data). Lake Mendota attracted 62,000 canvasbacks in 1954.

A major shift in fall concentration sites from southeastern Wisconsin to the UMR was evident in the mid- to late-1960s (Serie et al. 1983; G. Jolin and J. Dunn, unpubl. data). Peak counts in 1963 and 1964 for the Winnebago Pool Lakes were 30,000 and 28,000, respectively (G. Jolin and J. Dunn, unpubl. data). Although no data were collected from 1965-67, comparable surveys in 1968 and 1969 revealed only 835 and 620 canvasbacks, respectively; the maximum count from 1968 to 1990 was 5,500 in 1980. Survey data are insufficient for assessing the relative contribution of other sites in southeastern Wisconsin from 1964 through 1984. Of 15 sites censused during 1985-90, only Lake Poygan attracted more

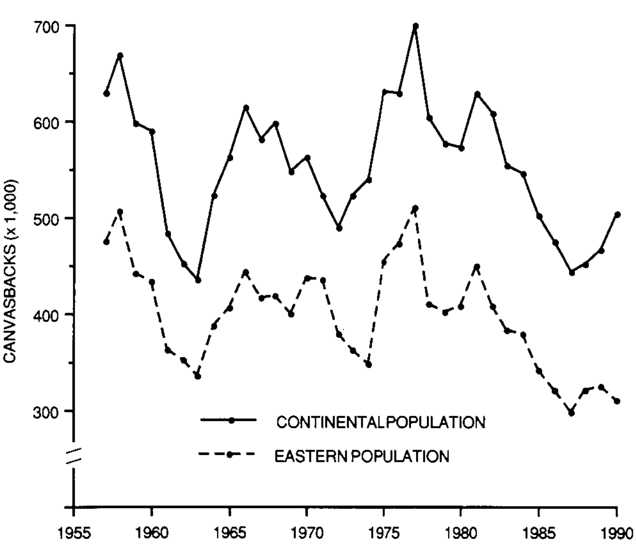


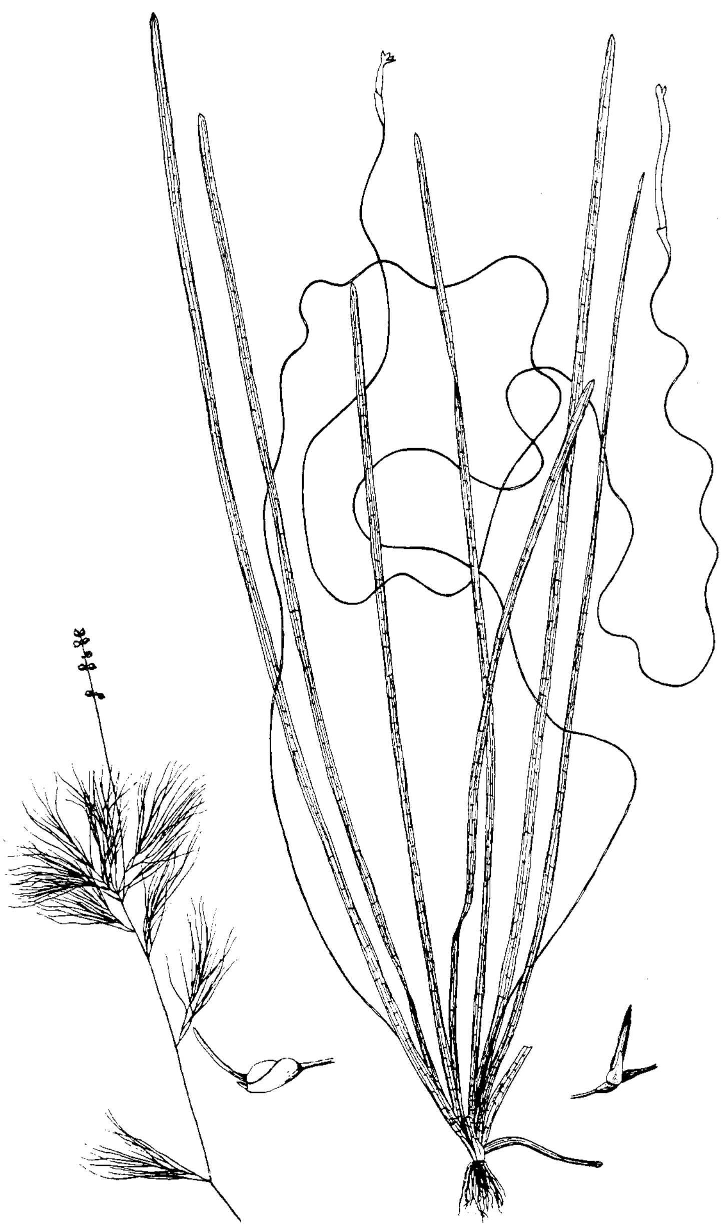
Figure 2. *Breeding populations of canvasbacks, 1955-90, from aerial breeding ground surveys, with 3-year averages plotted on the third year (Bartonek 1990). Small sample sizes in breeding ground survey data contribute to the variation in breeding population numbers.*

Figure 3. *Sites historically important to migrating canvasbacks in Wisconsin.*

than several hundred canvasbacks during fall of the same period; it hosted a maximum of 1,500 in 1989 (Kahl 1990; G. Jolin and J. Dunn, unpubl. data). In contrast, Pool 19 of the UMR attracted peak fall populations of < 40,000 from 1961 to 1965 and peak populations > 50,000 from 1965 to 1977 (Serie et al. 1983). Peak populations exceeded 100,000 in 1969-71, 1975, and 1977. At Pools 7-8 of the UMR, peak fall populations slowly increased from < 10,000 prior to 1964 to > 100,000 in 1974, 1975, and 1977 (Serie et al. 1983). Peak fall populations for Pools 7-9 fluctuated between 60,000 and 197,000 during 1978-84 (C. Korschgen, pers. comm.).

Although evidence suggests that staging populations in southeastern Wisconsin remain low, populations are quite dynamic and transient (R. Kahl, Wis. Dep. Nat. Resour., unpubl. data). In recent years, various sites apparently have attracted relatively large flocks, but these flocks often remained at a given site for only a few days or less.

CRITICAL COMPONENTS OF CANVASBACK STAGING HABITAT



Sago pondweed, with tuber (left) and wildcelery, with portion of rootstalk and bud (right) (illustrations courtesy of the Minnesota Department of Natural Resources: Moyle and Hotchkiss 1945).

Factors common to most canvasback staging habitats include a large open-water area affording some refuge from disturbance and extensive shallow areas or littoral zones supporting large beds of wildcelery and sago pondweed or high densities of macrobenthos, especially fingernail clams.

Food

Submerged macrophytes, primarily winter buds and tubers of wildcelery and sago pondweed (McAtee 1917, Cottam 1939, Anderson 1959, Anderson and Low 1976, Korschgen et al. 1988), typically comprise foods of migrating canvasbacks, but macrobenthos, especially snails and small clams, have become increasingly important in some locations after the decline in abundance of submerged macrophytes on several staging and wintering habitats (Stewart 1962, Perry 1975, Bellrose 1978, Bellrose et al. 1979). Loss of aquatic macrophytes followed by declining macrobenthos populations in the Illinois River Valley prior to the mid-1950s forced staging populations of canvasbacks to shift to pools of the UMR, especially Pool 19 at Keokuk, Iowa (Mills et al. 1966, Bellrose et al. 1979). At Pool 19, canvasbacks fed primarily on fingernail clams and other macrobenthos, which were abundant, and they fed little on submerged macrophytes, which were sparse (Thompson 1973). Canvasbacks staging on Pools 7-9 of the UMR during the 1970s and 1980s consumed primarily wildcelery winter buds (Korschgen et al. 1988). Habitat deterioration of migrational sites typically has been manifested in high water levels, increasing water turbidity, and algal populations that have caused the decline of submerged macrophytes and macrobenthos (Mills et al. 1966; Trauger and Serie 1974; Bellrose et al. 1979; Kahl, in press *a*).

Refuge From Human Disturbance

Excessive disturbance can reduce habitat suitability, although canvasbacks will tolerate some disturbance by altering daily activity patterns if areas with limited disturbance are available for loafing and roosting (Thornburg 1973; Kahl, in press *b*). But disturbance often causes a greater energy demand due to increased flight time coupled with less time for feeding. For example, boating disturbance to canvasbacks on Lake Poygan in spring and fall 1986-87 caused canvasbacks to take flight an average of once per hour and increased their daily energy requirements by 14-42 kcals (Kahl, in press *b*). This boating disturbance also contributed to canvasback avoidance of feeding areas for 29-63% of available daylight feeding time. This type of disturbance to canvasbacks is increasing due to increased aquatic recreation. Boating activity and size of boats and motors have been increasing nationally (Clawson and Van Doren 1984, U.S. Coast Guard 1990) and in Wisconsin, where fishing activity is the most frequent activity of boaters (Penaloza, in press). Technological advances in equipment allow greater accessibility and comfort during colder weather conditions, thus extending the boating season later into the fall. Additionally, continued lakeshore development likely has increased disturbance (Liddle and Scorgie 1980) and has led to conflicts over management of aquatic macrophytes, including wildcelery and sago pondweed, which are often considered undesirable by lakeshore property owners (Wis. Dep. Nat. Resour. 1989*b*).

Distribution of Migrational Staging Habitat

To ensure integrity between breeding and wintering sites, suitable staging habitat providing adequate food resources and refuge from disturbance must be strategically dispersed along or near traditional migration routes (North. Prairie Wildl. Res. Cent. 1982).

The loss of staging habitat and redistribution of canvasbacks threaten populations due to: (1) their susceptibility to catastrophic events (e.g., disease, oil and toxic chemical spills, and industrial accidents), (2) the potential for habitat deterioration on the last remaining sites, and (3) stress on body condition and reserves during migration (especially for females and juveniles) due to lack of food resources adequately distributed along migration routes (Trauger and Serie 1974, North. Prairie Wildl. Res. Cent. 1982, U.S. Fish and Wildl. Serv. 1984).

Adequately distributed food resources on staging habitats may also have important cross-seasonal impacts on canvasback populations. Migrating canvasbacks have relied on these staging habitats to replenish and build the fat reserves necessary for further migration (Serie and Sharp 1989). Furthermore, fat reserves during fall may affect winter survival (Haramis et al. 1986, Serie and Sharp 1989), while fat reserves during spring may affect productivity on the breeding grounds (Korschgen 1977, Ankney and MacInnes 1978, Krapu 1981).

Canvasbacks in flight from boating disturbance.

MANAGEMENT GOALS FOR WISCONSIN CANVASBACK POPULATIONS

Population Goals

Cooperate in achieving the proposed goal for the Upper Midwest to redistribute 50% (Oetting 1985) of the 2.5 million annual use-days for staging populations of canvasbacks on Pools 7-9 of the UMR during 1979-84 (C.E. Korschgen, unpubl. data).

As Wisconsin's contribution, accommodate 625,000 use-days in southeastern Wisconsin during fall and spring through development of additional food resources and protection from disturbance. This goal is much higher than present levels, which have averaged about 100,000 and ranged from 45,000-159,000 annual use-days for 15 sites in southeastern Wisconsin during 1986-89 (Kahl 1990; J. Dunn and G. Jolin, unpubl. data). This goal would accommodate present use and allow for redistribution of 20% of the annual use-days from Pools 7-9 of the UMR. To achieve this goal would require, for instance, attracting about 15,500 canvasbacks to southeastern Wisconsin and supporting this staging population for about 20 days during spring and 20 days during fall or 20,000 canvasbacks for about 15 days during each season. Only experience will show whether this is possible, but at the very least alternative habitats will then be available if degradation occurs on existing sites.

Canvasbacks have responded to a lesser degree to habitat improvements from undesirable fish control projects at both Beaver Dam Lake and the DNR's Grand River Marsh Wildlife Management Area. For several years after a 1986-87 project to control undesirable fish in Beaver Dam Lake, peak fall populations increased from an average of 20 to about 200 during fall and from 125 to 2,100 during spring (Kahl, unpubl. data). The Grand River Marsh Wildlife Management Area was surveyed less consistently than Beaver Dam Lake, but few canvasbacks were noticed there from 1985-89, prior to a project to control undesirable fish. After the control project, peak populations of canvasbacks reached 375 and 1,700 during fall 1990 and spring 1991, respectively.

Location/Distribution of Staging Sites

Develop a minimum of 3 staging sites to accommodate the goal level of use-days in southeastern Wisconsin. Multiple sites will likely disperse flocks and thereby reduce the risk of disease, reduce the potential of a catastrophic event decimating a large segment of the population, and reduce the impact of habitat degradation and excessive disturbance on any one site (U.S. Fish and Wildl. Serv. 1984, Korschgen et al. 1985). Dispersal will increase viewing and hunting opportunities and quality.

Strategically locate the sites along or near present migration routes. Specific selection of sites should reflect historic and present use by canvasbacks.

Food Resources

Develop and maintain sufficient areas of moderately dense to dense food resources to support use-day goals in southeastern Wisconsin: 720 ha of wildcelery, 540 ha of sago pondweed, or 5,440 ha of macrobenthos (Table 1). These area goals for food resources include an expansion factor of 20%, to account for the inability of canvasbacks to fully and efficiently utilize all areas of food resources and to account for variability within these areas, especially the less productive outer margins. The large area for molluscs in part reflects the difficulty of delineating large homogeneous "beds" of molluscs for quantifying densities and biomass, as compared with beds of wildcelery and sago pondweed. Evidence also suggests that macrobenthos may provide a less efficient nutrient pathway for acquiring the necessary energy reserves for migrating and wintering than winter buds and tubers (Perry et al. 1986, Lovvorn 1987, Takekawa 1987). Canvasbacks may have to consume approximately 3 times more fingernail clams by wet weight than wildcelery or sago pondweed tubers to obtain the same amount of energy (Table 1). Furthermore, a winter bud may contain about 14 times the usable energy as that of a fingernail clam.

Distribute food resources over the 3 staging sites, with each site providing about 210,000 use-days annually. This distribution requires about 240 ha of wildcelery, 180 ha of sago pondweed, or 1,815 ha of mollusc beds per site. Lake Poygan presently supports 335 ha of wildcelery, which must be maintained, and adequate food resources must be developed at each of 2 additional sites.

For each site, distribute the food resources in 2-3 relatively dense beds to increase foraging efficiency, to provide alternative feeding areas, and to enhance refuge protection.

Refuge From Disturbance

Protect migrating canvasbacks from disturbance through the following management options: establishment of inviolate refuges, waterfowl protection areas that prohibit disturbance, no-wake or nonmotorized boating zones and other boating restrictions (through spatial or temporal lake-use zoning), restrictions on fishing and/or hunting, and voluntary compliance refuges coupled with strong information and education campaigns (Kahl, in press *b*). The best management options for each site will be determined by size

Table 1. *Energy availability, rate of consumption, and carrying capacity of wildcelery, sago pondweed, and fingernail clams for staging and migrating canvasbacks.*

	Food Type			
			Fingernail Clams	
Characteristic	**Wildcelery**	**Sago Pondweed**	**With Shell**	**Without Shell**
Energy content (kcal/g)				
Dry weight	3.92[a,b,c]	3.92[d,e]	1.51[f]	4.23[f,g]
Wet weight	1.00[a,b,c]	1.00[d,e]	0.28[f]	—
Apparent digestibility (%)	80[c]	80[d,e]	85[h]	—
Daily energy intake (kcal/individual)	540[i]	540[i]	540[i]	—
Daily consumption (g/individual)				
Dry weight	172	172	421	150
Wet weight	675	675	2,269	—
Standing biomass				
Dry weight (g/m^2)	35.6[a,c,j]	50.0[d]	23.3[f,k]	—
Wet weight (g/m^2)	139.1[a,b,c]	—	125.3[f]	—
No. of food items (no./m^2)	186[a,c]	—	18,000[k]	—
Annual exploitation rate (%)	50[b]	48[d,l]	25[k,m]	—
Carrying capacity (use-days/ha)	1,035	1,395	138	—

[a] Donnermeyer 1982; from Pool 9 of the Upper Mississippi River, Wis.

[b] Korschgen et al. 1988; Korschgen, pers. comm.; from Pool 7 of the Upper Mississippi River, Wis.

[c] Takekawa 1987; from Pool 7 of the Upper Mississippi River, Wis.

[d] Anderson and Low 1976; from Delta Marsh, Manitoba.

[e] Assumed similar to wildcelery with similar nutrient composition.

[f] Thompson and Sparks 1978; from Pool 19 of the Upper Mississippi River, Ill. and Iowa.

[g] Brey et al. 1988; from a review of several studies on several species of bivalves and gastropods.

[h] Lovvorn 1987; from a review of several studies.

[i] Calculated from data in Takekawa 1987; 19.4% of day feeding (16,762 sec), diving time of 14.8 sec, total dives/day of 1,133, foraging efficiency of 0.86 winter buds/dive, daily consumption of 974 buds/day, and apparent metabolizable energy of 0.554 kcals/winter bud.

[j] Korschgen and Green 1988; from Pool 7 of the Upper Mississippi River, Wis.

[k] Thompson 1973; from Pool 19 of the Upper Mississippi River, Ill. and Iowa.

[l] Sterling 1970; from Bear River Refuge, Utah.

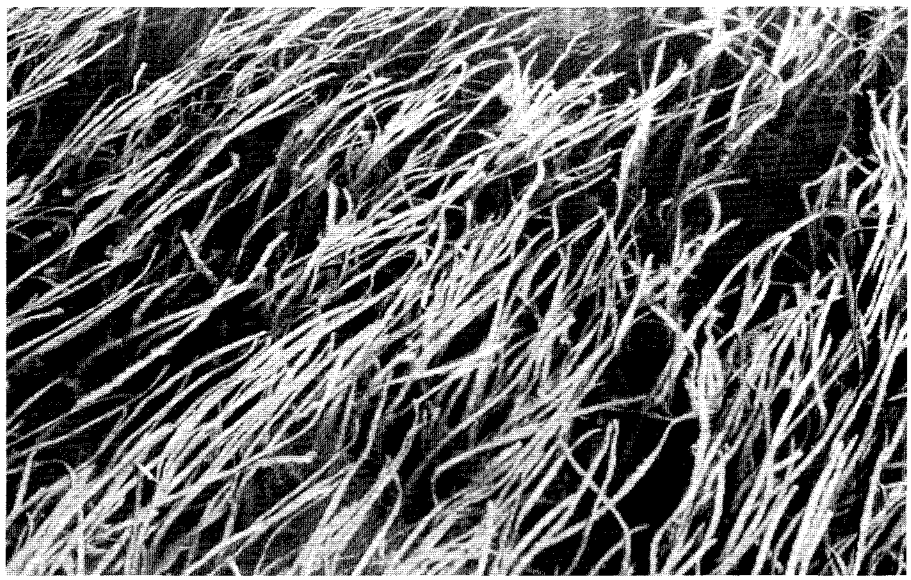
[m] Gale 1969; from Pool 19 of the Upper Mississippi River, Ill. and Iowa.

and configuration of open water at the site, distribution of food resources, hunter behavior, fall and spring fishing pressure, recreational boating patterns, and shoreline development patterns. Canvasbacks and other diving ducks will tolerate some disturbance if the area is large enough for birds to temporarily escape to undisturbed waters for loafing and roosting and if food is accessible during part of each day (possibly at least 40%, i.e., 9-10 hours: Day 1984, Takekawa 1987) (Thornburg 1973; Kahl, in press *b*). Large oval or round water bodies with prohibited open-water hunting may provide adequate protection. However, fishing and recreational boating activity on many sites can result in excessive disturbance in both fall and spring. Frequent boating disturbance from hunters and anglers has been documented for several staging sites (Korschgen et al. 1985, Kahl, in press *b*). See Appendix A for more information on these management strategies.

- If inviolate refuges or waterfowl protection areas are established, configure them to encompass at least 250 ha in a square or round shape with a buffer zone of at least 0.8-1.0 km on all sides (Korschgen et al. 1985; Kahl, in press *b*). Actual size and configuration will depend on the degree of inviolateness. Including a feeding site in the refuge may be essential if disturbance restricts access to food resources elsewhere. Refuges should be located to restrict the least number of users. Establishing inviolate refuges is the most effective option, but waterfowl protection areas coupled with strict enforcement can also be very effective. No-entry refuges are presently illegal on navigable waters in Wisconsin, since the Northwest Treaty Ordinance of 1787 and the federal legislation creating the State of Wisconsin and its constitution guarantee the right of free navigation on public, navigable waters.

- For no-wake or nonmotorized zones, configure them to encompass larger areas than refuges. This type of zoning will only be effective at some sites.

- Plan and implement an information and education campaign to increase public acceptance of the need for user restrictions, regardless of the management alternative selected.



A dense bed of wildcelery such as this one can produce winter buds to sustain about 1,000 canvasback use-days per hectare (photo by the author).

RESEARCH STRATEGY

Background

As assembly of baseline information for this research plan progressed, it became obvious that there were numerous information needs critical to the refinement and implementation of a management plan for achieving the goals just outlined. There was a lack of adequate data on canvasback staging populations, the availability of food resources for most staging habitats in Wisconsin, and the energy requirements of migrating canvasbacks. Rather than quantitative data, subjective estimates of canvasback use and food resources, based on experience of field managers, were the only available information for most sites. Additionally, there was a scarcity of recent data on water quality and other limiting or detracting factors for most sites. The literature review further revealed little quantitative study of the mechanisms and interrelationships of the major factors that are suggested as causative agents of habitat degradation. There also was a lack of information on the ecosystem processes and overall benefits to fish, wildlife, and water resources associated with management of these degradation factors.

The following plan outlines the research strategy for gathering baseline data prior to development of management plans. Management considerations and a general approach for accomplishing the goals set forth in this report are then outlined in Appendix A. Information in this appendix on the factors contributing to habitat degradation indicates the complexity and interrelatedness of these factors and justifies the recommended approach of comprehensive ecosystem management for large, shallow lakes.

Strategy

This research strategy embodies a step-by-step approach for obtaining the baseline information necessary to formulate restoration plans for canvasback staging habitat and populations. First, the present status of canvasback staging populations and staging habitat in southeastern Wisconsin should be determined. Next, factors limiting abundance of aquatic macrophytes and macrobenthos on the study sites should be identified; only then can appropriate restoration techniques be recommended and evaluated. The experimental design should incorporate evaluation for some restoration techniques (e.g., transplanting of submerged macrophytes, exclusion of undesirable fish and waves from experimental plots, breakwaters). Other techniques should be evaluated through cooperation in ongoing management projects (e.g., watershed management, water level management, control of undesirable fish, large-scale breakwaters). For example, a project for eradication of undesirable fish in Beaver Dam Lake (Congdon 1985) provides the opportunity to evaluate responses of water quality, submerged macrophytes, and canvasbacks to removal of undesirable fish from a large, shallow lake.

The proposed research strategy has 4 components:

Determine the present status of canvasback staging populations through spring and fall aerial censuses and incidental observations by field personnel. (Assumes continental populations will continue to be monitored.) Determine energy requirements, strategies, and the cross-seasonal energetic relationships for canvasbacks during migration, which may affect winter survival and reproductive output.

Determine the status of staging habitat, including abundance of foods (preferred species of submerged macrophytes and macrobenthos), water quality, and the magnitude, sources, and effects of disturbance.

Assess factors limiting aquatic macrophytes and macrobenthos.

Water quality. Determine the photic zone and maximum depth of colonization by submerged macrophytes in study lakes. Assess response of macrophyte changes to annual fluctuations in water clarity. Determine factors responsible for light attenuation by measuring light availability, chlorophyll *a* and *c*, turbidity, total and inorganic suspended solids, true color, and epiphyton and phytoplankton populations. Determine sources of nutrients and suspended solids. Determine dissolved oxygen (DO) and temperature profiles and formation of toxic compounds such as ammonia N. Determine bottom substrate suitability for macrophytes and macrobenthos. Determine relationships between macrophytes and macrobenthos.

Undesirable fish. Compare macrophyte and macrobenthos abundance to water quality parameters in protected vs. exposed sites in study lakes, or compare pre- and post-treatment conditions for control projects targeting undesirable fish. Determine undesirable fish population densities and food habits to assess their foraging impacts on macrophytes, macrobenthos, and water quality.

Wave action. Determine relationships between wind, waves, and water quality parameters for study lakes and site-specific locations. Compare macrophyte and macrobenthos abundance, water quality parameters, sources of turbidity (degree of sediment and nutrient resuspension), wave characteristics, and sediment type and fertility in protected study areas vs. adjacent control areas or compare pre- and post-treatment conditions for wave barrier projects. Determine relative contribution and impact of boating activity to wave action.

Water level fluctuation. Compare seasonal and annual water levels with water clarity and abundance of aquatic macrophytes.

Toxic contaminants. Determine presence and sources of contaminants in sediments, water, invertebrates, fish, and wildlife.

Evaluate restoration techniques.

Watershed management. Cooperate on other DNR projects to monitor water quality changes and aquatic macrophyte and macrobenthos response during and after implementation of watershed management plans.

Water level management. Determine aquatic macrophyte and macrobenthos response to seasonal and annual fluctuations in water levels and cooperate on other DNR projects to monitor response of aquatic macrophytes and macrobenthos during and after implementation of water level management plans.

Breakwaters. Clarify the ecological mechanisms and impacts of wave action on aquatic systems. Evaluate breakwater designs for effectiveness of wave attenuation, improvements in water quality, and changes in sediments and abundance of aquatic macrophytes and macrobenthos. Evaluate techniques for the establishment of emergent macrophytes as living breakwaters and evaluate wave and water quality responses.

Re-establishment of submerged macrophytes. Evaluate planting techniques, water quality and macrobenthos response, and wave attenuation.

Control of undesirable fish. Clarify the ecological processes leading to the development of excessive undesirable fish populations, their impact on aquatic ecosystems, and long-term control techniques. Evaluate control or exclusion projects targeting undesirable fish by monitoring responses of water quality, aquatic macrophytes, and macrobenthos. Compare commercial and DNR harvests of undesirable fish to water quality and aquatic macrophyte and macrobenthos abundance. Identify species-specific attractants, toxicants, sterilants, and/or treated baits.

Waterfowl protection areas. Evaluate the effectiveness of refuges, boating restrictions, and/or hunting and fishing restrictions in reducing boating disturbance to waterfowl.

STUDY SITES

Sites in southeastern Wisconsin with the highest potential for attracting canvasbacks include lower Green Bay; Lakes Poygan, Winneconne, and Butte des Morts of the Winnebago Pool; Lake Koshkonong; Lake Puckaway; and Lake Petenwell (R. Kahl, unpubl. data). However, the presence of toxic materials from industrial pollution, relatively great water level fluctuations, and little opportunity for controlling these factors limit the management potential of both lower Green Bay (U.S. Fish and Wildl. Serv. 1979, Harris et al. 1982) and Lake Petenwell (Kleinert and Degurse 1972; R. Martini, Wis. Dep. Nat. Resour., pers. comm.). Thus, Lakes Poygan, Winneconne, Butte des Morts, Koshkonong, and Puckaway were selected as the sites providing the best opportunities for both research and management (Fig. 3). These sites all have experienced moderate to severe habitat degradation caused by high and fluctuating water levels, wave and ice action, sedimentation, eutrophication, and undesirable fish (although the relative importance of each factor varied from site to site) (Zimmerman 1953; Threinen and Helm 1954; Thompson 1959; Jahn and Hunt 1964; Wis. Dep. Nat. Resour. 1969; Kahl, in press *a*). These factors continue to limit habitat quality at each of these sites. (See Appendix A for a detailed presentation of the sources and effects of these factors.) Selection criteria, historical perspective, and present conditions and problems of each site are described below. The Bureau of Research also will collaborate with the Bureaus of Wildlife Management, Fisheries Management, Water Resources Management, and Endangered Resources to evaluate present or planned restoration activities pertinent to canvasback habitat management at other sites having potential for canvasback staging habitat, such as Beaver Dam Lake, which is described along with the other study sites below.

Upper Winnebago Pool Lakes: Poygan, Winneconne, and Butte Des Morts

Overview

This large, shallow system could provide a variety of feeding, loafing, and roosting sites for canvasbacks. Lakes Poygan (5,670 ha), Winneconne (1,822 ha), and Butte des Morts (3,645 ha) encompass approximately 11,140 ha and have maximum depths of approximately 3.3 m, primarily in the old river channels (Fassbender and Nelson 1975). These lakes were the most important staging habitat for canvasbacks during 1947-65, and Lake Poygan continues to attract several hundred to several thousand canvasbacks each spring and fall (G. Jolin and J. Dunn, unpubl. data). These lakes presently support a limited amount of wildcelery and sago pondweed (approximately 375 ha, primarily in Lake Poygan) (R. Kahl, unpubl. data). There is considerable interest in system rehabilitation—a comprehensive management plan was completed in 1989 (Wis. Dep. Nat. Resour. 1989*a*), and implementation was begun in 1989-90. As part of this plan, large-scale breakwater projects have been proposed to protect and enhance aquatic vegetation in several locations in the system. The first breakwater project would improve water clarity in a bay in southwestern Lake Butte des Morts by redirecting turbid inflow from the Fox River past the bay and by reducing marsh-edge erosion and resuspension of sediments by waves. These projects could allow wildcelery and sago pondweed to colonize large areas inside the break walls, thus greatly benefitting canvasbacks. Furthermore, data are available from a previous research project (Kahl, in press *a*).

Historical Perspective

In the 1800s, these lakes were large riverine marshes supporting dense emergent macrophytes dominated by annual wildrice (Linde 1979). The characteristics of this ecosystem have changed dramatically since then, as summarized by Kahl (in press *a*).

Impoundment in the mid-1800s increased water levels by about 0.61 m, eliminating emergent macrophytes in the deepest areas and creating floating bogs of dense rhizomatous mats of wetland vegetation over large areas. Water level management in the late 1800s and early 1900s, dictated by transportation and flood control objectives, required winter drawdowns and rapidly increasing water levels in early spring. Rising water levels in spring prior to ice-out created more floating bogs when ice formed in surface sediments and tore the surface sediments and attached root systems of perennial emergent macrophytes from bottom substrates. Wave action also created bogs, as unstable sediments were scoured from beneath rhizomatous mats. Subsequent ice and wave action then disintegrated these floating bogs, creating small floating islands of emergent macrophytes that were readily carried downstream, especially in years of high water (Fig. 4). As emergent macrophytes decreased, expanses of open water increased, thus allowing greater wave action and further exacerbating the problem. These events probably created suitable habitat for deep-water emergent and submerged macrophytes by providing moderate water depths and by eliminating competition by shallow-water species. Deep-water emergent and submerged macrophytes probably quickly colonized the increasing open-water areas. Most bogs and shallow-water macrophytes had disappeared by the 1930s (Kahl, in press *a*).

Photo by Herb Lange.

In 1937, improvements in water level control structures allowed an additional 0.15 m increase in average summer water levels, which remained consistently higher during 1938-73 than during 1896-1937. Submerged macrophytes and deep-water emergent macrophytes were abundant but slowly declining through the late 1950s and early 1960s. In the early 1960s, the decline of these macrophytes apparently accelerated rapidly. There is no evidence that mean and maximum spring-summer water levels differed in the 1960s from those of the 1940s or 1950s, except for 1960, when water levels remained higher for a longer period than in any year since 1929. The factors contributing to loss of deep-water emergent and submerged macrophytes in the 1960s are therefore not readily apparent, but probably include severe flooding or water level fluctuations (such as in 1960), eutrophication and turbidity due to municipal wastewater discharges, nonpoint pollution from agricultural lands and lakeshore developments, and/or undesirable fish (Kahl, in press *a*).

After this major decline in deep-water emergent and submerged macrophytes in the early 1960s, high turbidity prevailed, presumably also due to nonpoint pollution and undesirable fish as well as increased availability of nutrients for phytoplankton and the resuspension of bottom materials by wave action. Severe and prolonged flooding occurred again in 1969 and 1973. As submerged macrophytes declined and turbidity increased, predator fish populations probably declined, allowing growth of undesirable fish populations. Increased turbidity, wave action, undesirable fish populations, and continued high water would then prevent or severely limit recolonization by submerged macrophytes (Kahl, in press *a*).

Peak fall canvasback populations on this site decreased from approximately 30,000 in the early 1960s to 600-800 in the late 1960s; fall populations of most other waterfowl species decreased similarly (Jahn and Hunt 1964; G. Jolin and J. Dunn, unpubl. data). Game fish populations likely also declined during this period due to increasing turbidity and loss of aquatic macrophytes (Kahl, in press *a*).

Present Conditions and Problems

The primary problems affecting present habitat quality include high and fluctuating water levels, wave and ice action, sedimentation, eutrophication, and undesirable fish (Wis. Dep. Nat. Resour. 1989*a*; Kahl, in press *a*).

Water levels. A water level management plan was cooperatively implemented in 1981-82 by the DNR and the U.S. Army Corps of Engineers to stabilize seasonal water levels and to maintain relatively low late-winter early-spring levels until after ice-out (Linde 1980; Kahl, in press *a*). This plan continues to be modified and refined to better meet these objectives as well as an additional objective of delaying winter drawdown until after freeze-up to enhance aquatic furbearer survival (Kahl, in press *a*). Implementation of the plan has failed to reduce average late-spring early-summer water levels (Kahl, in press *a*). Consistently high water levels in May and June may thus ultimately control the long-term abundance of aquatic macrophytes in this large, shallow system.

Wave action. Wave action from wind and boats has been suggested as a major factor limiting re-establishment and growth of aquatic macrophytes by direct physical damage and increased turbidity (Jupp and Spence 1977). Wind-generated waves may limit re-establishment of aquatic macrophytes in the Upper Winnebago Pool Lakes, but waves probably do not directly affect existing beds of most species of submerged and deep-water emergent macrophytes except during infrequent severe storms (Kahl, in press *a*). However, wind-induced wave action contributes to turbidity on these lakes during spring and summer (Kahl 1990; Kahl, in press *a*). There are few aquatic macrophytes or other structure in the large open-water areas to attenuate wave action. Shoreline and marsh-edge protection through rip-rapping has produced visible benefits by stabilizing these areas, and this management practice should continue.

Water clarity. The Pool Lakes are very turbid, with average summer turbidities higher than for most Wisconsin lakes (Lillie and Mason 1983; Kahl, in press *a*). Water clarity is typically better for Lakes Poygan and Winneconne than for Lake Butte des Morts. During 1986-89, spring Secchi disc transparencies ranged from 65-71 cm for Lake Butte des Morts and 70-87 cm for Lakes Poygan and Winneconne; summer transparencies ranged from 44-55 cm for Lake Butte des Morts and from 52-64 cm for Lakes Poygan and Winneconne (R. Kahl, unpubl. data). During spring 1986-89, the 5% photic zone extended to 102-121 cm for Lake Butte des Morts and to 117-154 cm for Lakes Poygan and Winneconne (R. Kahl, unpubl. data). This photic zone decreased to summer averages of 78-89 cm in Lake Butte des Morts and 84-101 cm in Lakes Poygan and Winneconne.

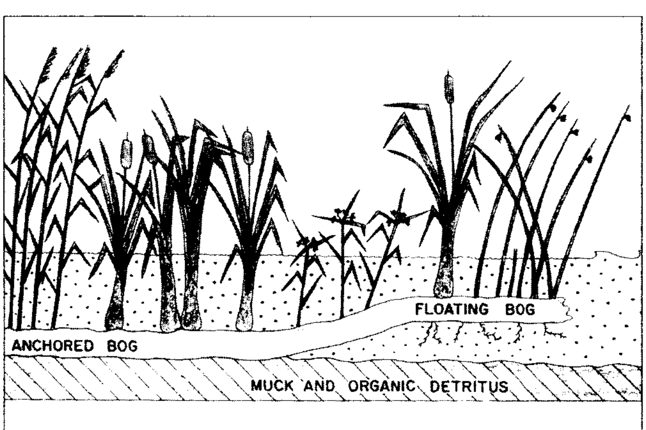
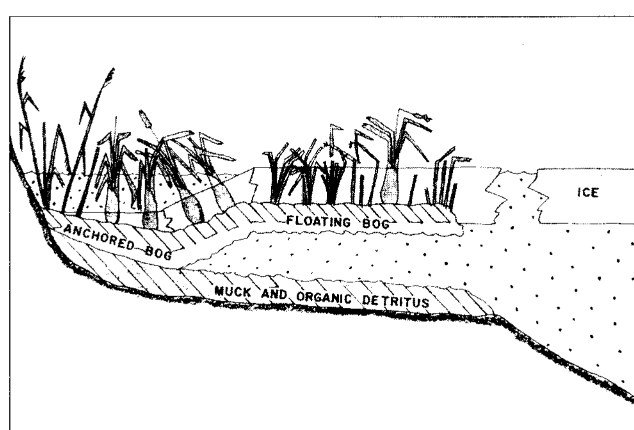


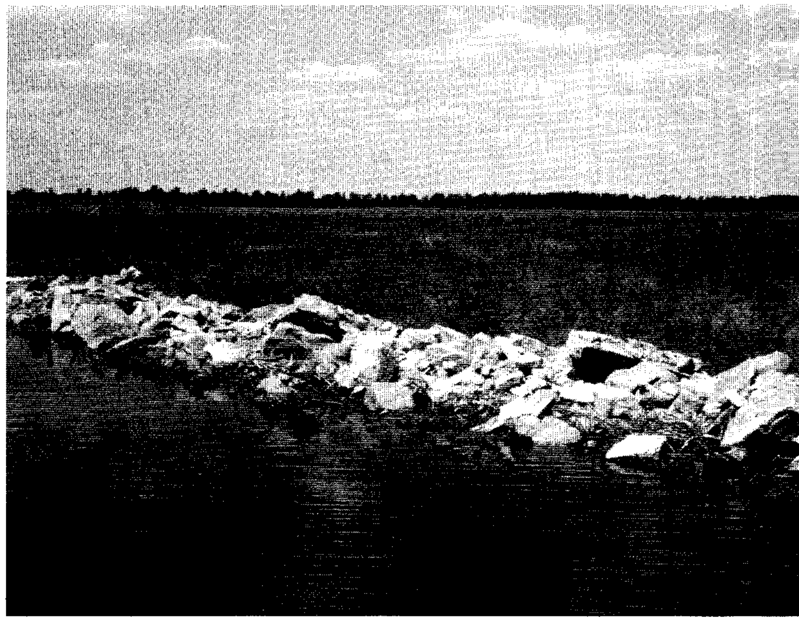
Figure 4. *Floating bogs are created when (a) high and fluctuating water levels lift dense rhizomatous mats away from underlying substrates;*



(b) rising water levels in spring prior to ice-out lift the ice layer formed within rhizomatous mats, tearing them away from bottom substrates;

Localized differences in water clarity, extreme turbidity, and high water in some years limits survival of submerged macrophytes to somewhat shallower zones in most locations (Kahl, in press *a*; R. Kahl, unpubl. data).

Important factors contributing to turbidity during spring likely include resuspension of bottom sediments and nutrients by waves and undesirable fish, eroding shorelines, and soil erosion. The most important factor contributing to turbidity in these lakes during summer appears to be phytoplankton blooms resulting from excessive nutrient loading (Sloey 1970; Sloey and Spangler 1977; Kahl 1989; Kahl, in press *a*). External sources that contribute approximately 50% of excessive nutrient loading include agricultural and other rural nonpoint sources (70% of total external), municipal sources (10%), and septic tanks, urban runoff, and dredging (6%) (U.S. Environ. Prot. Agency 1974, 1975). Internal nutrient loading contributes 50% of summer phosphorus, primarily from sediment release but also from recycling and resuspension by undesirable fish, benthos, and waves (Laumer 1977, Sloey and Spangler 1977, Wiersma et al. 1977).

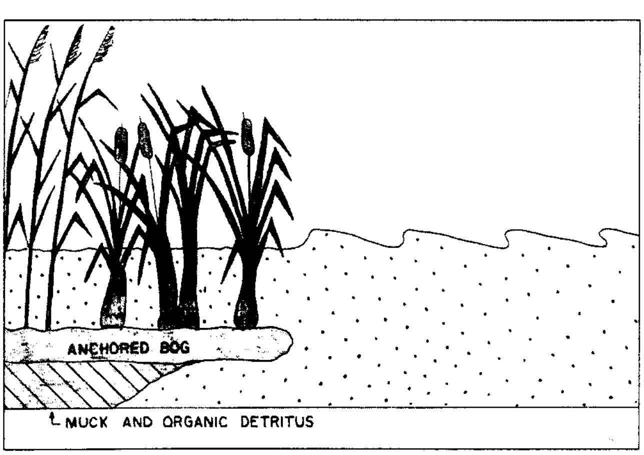


Dense stands of wildrice and other emergent macrophytes have colonized some areas protected by riprap wave barriers on the Winnebago Pool lakes (photo by Arlyn Linde).

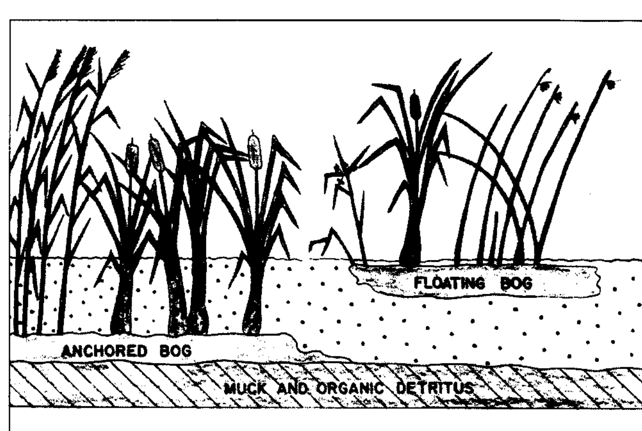
Due to the short retention time of the Pool Lakes (U.S. Environ. Prot. Agency 1974, 1975), improvements in the watershed potentially would dilute or flush nutrients and improve water clarity. The degree of improvement would depend on the long-term magnitude of internal loading and the extent of turbidity caused by other sources such as undesirable fish and wave action. For long-term improvements, a watershed master plan must be developed and implemented. The comprehensive management plan for the Winnebago system (Wis. Dep. Nat. Resour. 1989*a*) specifies a watershed management strategy for implementation by the year 2000.

Undesirable fish. Carp populations apparently are not excessive in the Pool Lakes, but periodic localized damage probably occurs from spawning and feeding concentrations (Otis and Weber 1982; Weber and Otis 1984; Kahl, in press *a*; D. Folz, Wis. Dep. Nat. Resour., pers. comm.). Excessive populations of freshwater drum (Priegel 1971) may contribute significantly to turbidity. Although data are lacking, undesirable fish likely are one of the major causes of turbidity and internal nutrient cycling in these lakes (Laumer 1977, Sloey and Spangler 1977). The impacts of excessive undesirable fish populations on water clarity and aquatic macrophytes have been demonstrated in numerous studies at other locations (Tryon 1954, Robel 1961, Lamarra 1975, Andersson et al. 1978, Tatrai and Istvanovics 1986). However, long-term, intensive removal of freshwater drum from Lake Winnebago did not substantially improve the sport fishery (Priegel 1971, Otis 1988). Benefits of this program are currently being reviewed.

Sediments. Bottom substrates apparently consist of sand/silt sediments in the shallower zones and soft muck in the deeper zones that are relatively undisturbed by waves (Harrison 1970, McKee and Laudon 1972, Fassbender and Nelson 1975). Several protected shallow bays also have soft, mucky sediments.



(c) substrates under rhizomatous mats are scoured away.



(d) Wave and ice action then break these bogs into small islands that float downstream (illustrations by Arlyn Linde and Tom Janisch).

Littoral zone. Approximately 10-20% of the surface area of these lakes has water depths < 100-140 cm (maximum depth of colonization by submerged macrophytes); approximately 10% has water depths < 90 cm (Fassbender and Nelson 1975). Obviously, since submerged macrophytes have colonized only 5% of the total area, factors other than lakewide water clarity affect abundance and distribution (R. Kahl, unpubl. data). These factors likely include localized differences in water clarity, sediments, undesirable fish activity, and wave action (Kahl, in press *a*).

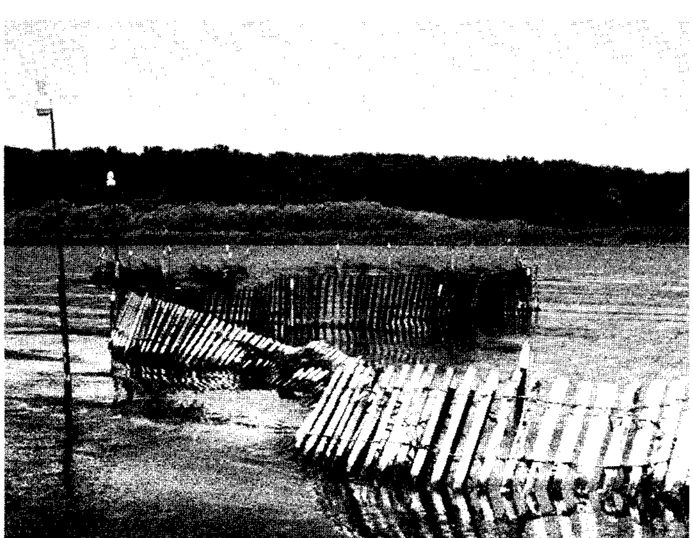
Submerged macrophytes. Area coverage of all species of submerged macrophytes totalled about 550-650 ha (5% of the total surface area) during 1986-89 (R. Kahl, unpubl. data). Wildcelery was dominant or co-dominant and sago pondweed was an important secondary species in most areas.

Macrobenthos. Preliminary results of an ongoing study to determine macrobenthos abundance in areas used by diving ducks in these lakes suggest that macrobenthos populations are moderately low to sparse (R. Kahl, unpubl. data).

Lake Koshkonong

Overview

This large, shallow lake offers expanses of open water for refuging and large littoral zones with potential for supporting submerged macrophytes. Lake Koshkonong encompasses 4,235 ha, with a maximum depth of about 2.1 m (Wis. Dep. Nat. Resour. 1969). In the late 1800s and early 1900s this site was the most important staging habitat for canvasbacks in the Midwest (Sinclair 1924, Frautschi 1945); it continues to attract a small core population of 50-650 canvasbacks each fall and presently supports a very limited amount of sago pondweed (Kahl 1990; R. Kahl, unpubl. data). There is interest within DNR and local sporting groups to actively manage the lake for improved fish and waterfowl habitat, including management of water levels, undesirable fish, and aquatic macrophytes.



A severe storm with strong winds damaged this wave barrier in Lake Koshkonong. The storm also damaged both the planting of sago pondweed that the barrier was installed to protect and a surrounding natural bed of sago pondweed as well (photo by the author).

Historical Perspective

In the early 1800s, this lake was a large riverine marsh with dense emergent macrophytes (especially wildrice), maximum water depths of 0.6 m, very clear water, and an excellent fishery comprised of bluegill, yellow perch, and largemouth bass (Sinclair 1924). A mill pond dam was constructed in the 1850s, apparently creating a shallow lake with less abundant emergent macrophytes but with dense submerged macrophyte populations, especially wildcelery and various pondweeds (Sinclair 1924, Main 1945, Threinen 1952, Jahn and Hunt 1964). A hydro-electric dam replaced the mill pond dam in 1917. This dam held water levels 0.9-1.2 m above the natural stage and resulted in extensive flooding in some years (Wis. Dep. Nat. Resour. 1969). Aquatic macrophytes declined precipitously due to high and fluctuating water levels, wave action, and an increasing undesirable fish population (Threinen 1952). Carp were introduced in the late 1800s or early 1900s, but were not considered a problem associated with habitat deterioration until the early 1920s, when game fish populations declined (Threinen 1952).

From the late 1800s through approximately 1917, Lake Koshkonong was known throughout North America as one of the premier canvasback hunting lakes in the U.S. (Jahn and Hunt 1964). Market hunters harvested thousands of birds to be shipped to Chicago and large eastern cities, where they were served in fine hotels and restaurants (H. Stroebe, Wis. Dep. Nat. Resour., unpubl. data). Other species of diving ducks and coots were also attracted to the lake in large numbers. However, after aquatic macrophytes declined in the 1920s, Lake Koshkonong attracted relatively few diving ducks or other waterfowl (Threinen 1952, Jahn and Hunt 1964).

From 1920-52, several periods of temporary habitat improvement occurred (Threinen 1952). These apparently were associated with winterkills that reduced populations of both undesirable fish and game fish, resulting in increased vegetation, quickly rebounding game fish populations, and a slight positive response by diving ducks. During 1940-43, water was very turbid, with Secchi disc transparencies of 15-75 cm (Zimmerman 1953). The sparse submerged macrophytes consisted primarily of sago pondweed, bladderwort, and coontail.

Present Conditions and Problems

The primary problems affecting present habitat quality are eutrophication, undesirable fish, high and fluctuating water levels (especially flooding in spring), wave action, sedimentation, and ice damage (Threinen 1952, Wis. Dep. Nat. Resour. 1969).

Water levels. Average spring and summer water levels have varied considerably in recent years. However, implementation of a water level management plan has partially stabilized and reduced water levels. Flooding typically occurs throughout April and May, due to high flows in the Rock River and a constricted channel at the lower end of the lake that restricts outflow (Candeub, Fleissig and Assoc. 1966; Krug and House 1984).

Wave action. Severe wave action occurs due to the southwest-northeast orientation of the lake, which produces the longest possible fetch for prevailing summer winds. This large, shallow lake has few aquatic macrophytes or other structure to attenuate wave action (Threinen 1952, Wis. Dep. Nat. Resour. 1969). In attempts to re-establish sago pondweed in this lake, severe wave action damaged wave barriers and negatively impacted the plantings.

Water clarity. Extremely turbid water conditions prevail, with spring and summer Secchi disc transparencies of 47-73 cm and 18-59 cm, respectively, during 1986-89 (R. Kahl, unpubl. data). For the same period, the depth of the 5% photic zone was 76-118 cm for spring and 29-93 cm for summer. Excessive phytoplankton populations cause most turbidity during late spring and summer (R. Kahl, unpubl. data).

Undesirable fish. Extremely dense undesirable fish populations (primarily carp) likely contribute significantly to poor water quality and physical damage to aquatic macrophytes (Threinen 1952, Threinen and Helm 1954).

Sediments. Bottom substrates consist of about 70% muck, 15% sand, 10% rubble and 5% gravel (Wis. Dep. Nat. Resour. 1969; D. Bush, Wis. Dep. Nat. Resour., pers. comm. 1985). Depending on the consistency and distribution of the muck and sand materials, 85% of the bottom sediments potentially are suitable for colonization by aquatic macrophytes.

Littoral zone. Approximately 20% of the surface area has depths < 120 cm, and 10% has depths < 90 cm (Wis. Dep. Nat. Resour. 1969). Therefore, the 5% photic zone covers approximately 10% of the surface area during the crucial spring growth period. However, this area will vary considerably, depending on annual variations in water levels and turbidity.

Submerged macrophytes. Abundance of submerged macrophytes (primarily sago pondweed) varies from year to year, but generally covers a very small part of the lake (approximately 1-2%). Less than 40-80 ha of sago pondweed existed in 1986-89 (R. Kahl, unpubl. data). Factors limiting aquatic macrophytes probably include turbidity, carp populations, spring and summer water levels, and frequency of severe storms.

Macrobenthos. No information is available on macrobenthos abundance, but densities of some species of macrobenthos may be high, as evidenced by high ruddy duck use of this lake during migration (R. Kahl, unpubl. data). Ruddy ducks primarily consume macrobenthos at some staging and wintering areas (Steward 1962, Thompson 1973, Hoppe et al. 1986).

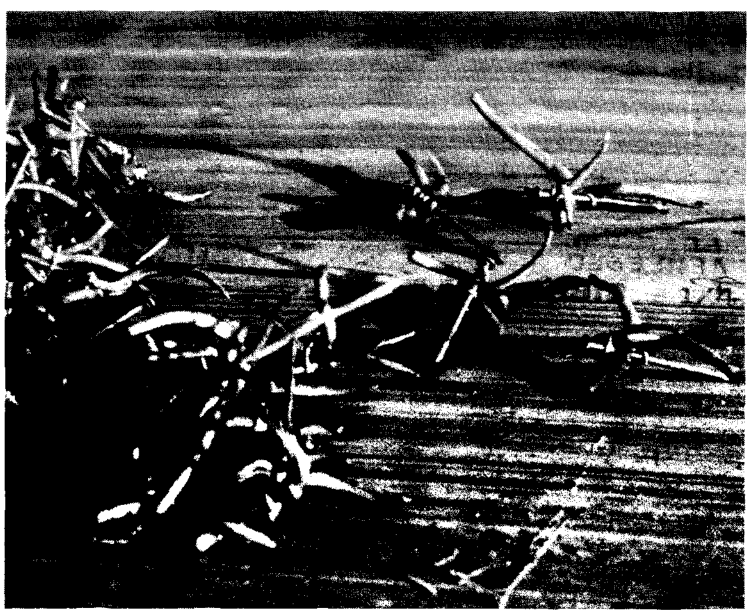
Historical Perspective

In the early- to mid-1800s, this lake was a riverine marsh with abundant aquatic macrophytes, especially wildrice (Thompson 1959). Impoundment in the mid-1800s increased water levels, which apparently created optimum conditions for development of dense submerged macrophyte beds, including wildcelery and pondweeds. The relatively large beds of submerged macrophytes and adjacent marshes attracted large fall populations of diving ducks and other waterfowl (Frautschi 1945, Zimmerman 1953).

Lake Puckaway

Overview

This moderately sized lake offers less expanse of open water for refuging, but it is the shallowest of the study sites, thus providing greater potential for aquatic macrophyte management. Lake Puckaway encompasses 2,187 ha with a maximum depth of about 1.8 m (Fassbender et al. 1970) and presently supports expanding beds of wildcelery and other aquatic macrophytes (R. Kahl, unpubl. data). In the late 1800s, Lake Puckaway was an important canvasback migrational site in Wisconsin (Frautschi 1945, U.S. Fish and Wildl. Serv. 1953); it continues to attract small flocks of 50-250 canvasbacks in fall of most years (Kahl 1990). Interest by the DNR, the local lake association, and local conservation groups has resulted in an active and successful management program, including planting of wildcelery, construction of breakwaters, carp control, and improved water level management (Brege and Congdon 1987).



Planting wildcelery winter buds in Lake Puckaway. (a) The Lake Puckaway Association provided partial funding and labor in a cooperative project with the DNR to re-establish wildcelery in several locations on the lake. (b) Note nails attached to winter buds as weights (photos by the author).

From 1900 to 1950, several periods of major vegetation loss occurred (apparently related to unusual weather patterns and high water levels), but with relatively rapid recovery (U.S. Fish and Wildl. Serv. 1953). Except for these brief periods of vegetation loss, habitat conditions and the wildlife and fishery resource remained in excellent condition until 1950. During 1940-43, water clarity was high and aquatic macrophytes were abundant (Zimmerman 1953). Dominant submerged macrophytes included wildcelery, coontail, watermilfoil, Canadian waterweed, naiad, and sago pondweed.

Although carp were introduced in the early 1900s, populations remained generally low until 1950, when a freak storm with high winds and several other complicating factors decimated aquatic macrophytes and apparently created conditions favorable to rapid carp population growth (Thompson 1959). From 1950 through the early 1980s, carp, soil erosion and siltation, and water level fluctuations seriously degraded fish and wildlife habitat (Thompson 1959; D. Brege, Wis. Dep. Nat. Resour., pers. comm. 1985). Conditions have improved since the early 1980s through intensified management efforts (Brege and Congdon 1987; R. Kahl, unpubl. data).

Present Conditions and Problems

The primary problems affecting habitat quality are high and fluctuating water levels, wind-induced wave action, eutrophication, sedimentation, and undesirable fish (D. Brege and R. Kahl, unpubl. data).

Water levels. Average spring and summer water levels have varied considerably from year to year. A water level management plan has partially stabilized and lowered spring and summer water levels (D. Brege, Wis. Dep. Nat. Resour., pers. comm. 1985).

Wave action. Although wave action apparently causes direct physical damage only during infrequent severe storms (U.S. Fish and Wildl. Serv. 1953), it probably contributes to turbidity whenever moderate to high west- or east-wind conditions prevail. The relatively narrow configuration of Lake Puckaway and a large peninsula formed by emergent macrophytes in the mid-lake area both confer considerable protection from wave action.

Water clarity. Spring and summer Secchi disc transparencies were 63-85 cm and 42-94 cm, respectively, during 1986-89 (R. Kahl, unpubl. data). During the same period, the depth of the 5% photic zone was 112-126 cm and 68-121 cm during spring and summer, respectively.

Undesirable fish. Carp control upstream, in-lake spot treatments of concentrations of spawning carp, and the installation of a weir at the lake outlet have all been successful in controlling carp; resulting habitat improvements include increasing water clarity and abundance of aquatic macrophytes (Brege and Congdon 1987; R. Kahl, unpubl. data).

Sediments. Bottom sediments are comprised primarily of silt and sand (R. Kahl, pers. obs.). Therefore, all of the bottom is suitable for colonization by aquatic macrophytes.

Littoral zone. The 5% photic zone likely reaches 30-40% of the lake bottom, although bottom contour information is lacking.

Submerged macrophytes. Submerged macrophytes cover about 285 ha or approximately 13% of the lake area (R. Kahl, unpubl. data). Limiting factors apparently include wave action, locally poor water clarity, and carp.

Macrobenthos. No information is available on macrobenthos populations.

Beaver Dam Lake

Overview

A 1986-87 project for eradication of undesirable fish (Congdon 1985) provided the opportunity to evaluate this technique as a management tool for large, shallow lakes with potential as canvasback staging habitat. Beaver Dam Lake encompasses 2,649 ha, with a maximum depth of about 2.1 m (Congdon 1985). Historically, Beaver Dam Lake was not an important canvasback migration site (Wis. Conserv. Dep. 1949, Jahn and Hunt 1964), but its location, size, and shallow depth confer high management potential for canvasbacks. Favorable response by canvasbacks to the eradication of undesirable fish (peak populations of 72-325 canvasbacks during fall and 252-2,350 during spring 1987-89) emphasizes the management potential of this site (Kahl 1990).

Historical Perspective

Although historical conditions are sketchy, this glacial lake basin apparently held little standing water prior to impoundment. The original dam was built in 1842-43 and was replaced or modified several times by the early 1900s; it eventually raised water levels to as much as 2.0-2.5 m (Wis. Conserv. Dep. 1949). Aquatic macrophytes were common in the late 1800s but were restricted primarily to sheltered bays and shorelines (Wis. Conserv. Dep. 1949). By the early 1900s aquatic macrophytes had declined considerably, due primarily to excessive water level fluctuations (up to 1.0 m annually) but also to siltation and shoreline erosion, increasing undesirable fish populations, and eutrophication from nonpoint pollution (Wis. Conserv. Dep. 1949). During 1940-43, high water turbidity and absence of most aquatic macrophytes contributed to relatively low fish and wildlife populations (Zimmerman 1953).

Partial winterkills have periodically favored carp and bullhead populations since the late 1800s. However, several severe winterkills during the 1900s greatly reduced even undesirable fish populations (Wis. Conserv. Dep. 1949, Congdon 1985). Aquatic macrophytes and desirable fish and waterfowl populations quickly responded. The most recent of these severe winterkills occurred in 1977-78 (Congdon 1985).

Present Conditions and Problems

The primary problems affecting habitat quality are undesirable fish, eutrophication, sedimentation, shoreline erosion, and wave resuspension (Kernen et al. 1965, Congdon 1985).

Water levels. A water level management plan adopted in 1939 reduced seasonal and annual water level fluctuations (Wis. Conserv. Dep. 1949), so that water levels presently are relatively stable.

Wave action. The relatively narrow, irregular configuration of this lake affords some protection from wave action. However, waves erode shorelines and probably readily resuspend the fine silt and clay sediments, especially the strong northwest-southeast winds that affect the main body of the lake (Wis. Conserv. Dep. 1949, Congdon 1985).

Water clarity. In 1986 spring and summer Secchi disc transparencies were 21 cm and 13 cm, respectively, prior to drawdown and eradication of undesirable fish (R. Kahl, unpubl. data). In 1988-89, after treatment, spring and summer transparencies were 111-138 cm and 48-82 cm, respectively (R. Kahl, unpubl. data). Depth of the 5% photic zone was 35 cm and 20 cm during spring and summer 1986, respectively. In 1988-89, after treatment, this depth increased to 170-176 cm and 74-84 cm during spring and summer, respectively (R. Kahl, unpubl. data).

Undesirable fish. Prior to treatment in 1986-87, the excessive carp population contributed to poor water quality and lack of aquatic macrophytes (Congdon 1985). The drawdown and eradication project in 1986-87 produced significant improvements in water clarity, aquatic macrophytes, and waterfowl populations in 1988 (R. Kahl, unpubl. data). However, high phytoplankton populations developed in 1989-90, apparently due to excessive eutrophication of sediments and nutrient loading from the watershed. This reduced the expected benefits to water quality and submerged macrophytes in 1989-90, although diving ducks and other waterfowl continued to use the lake in far greater numbers during spring and fall than before the treatment (Kahl 1990).

Sediments. Moderately firm silt and clay sediments, suitable for aquatic macrophyte colonization, cover most of the lake bottom (Kernen et al. 1965).

Littoral zone. The increased 5% photic zone resulting from eradication of undesirable fish likely reaches 25-35% of the lake bottom, although contour information is lacking.

Submerged macrophytes. Numerous small patches of submerged macrophytes became established in a widely scattered pattern over about 50% of the lake in 1988 (R. Kahl, unpubl. data). However, dense phytoplankton populations in late summer of 1988 and throughout summer 1989 apparently caused nearly complete loss of these macrophytes by mid-summer 1989 (R. Kahl, unpubl. data). The primary limiting factors for submerged macrophytes since eradication of undesirable fish likely are excessive eutrophication of bottom sediments and nutrient loading from the watershed.

Macrobenthos. No information is available on macrobenthos populations, but macrobenthos may be abundant since the drawdown and eradication of undesirable fish, as evidenced by the relatively high use of the lake by ruddy ducks and lesser scaup (Kahl 1990; R. Kahl, unpubl. data). Ruddy ducks and lesser scaup primarily consume macrobenthos at many staging and wintering sites (Stewart 1962, Rogers and Korschgen 1966, Thompson 1973, Perry and Uhler 1982, Hoppe et al. 1986).

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Staging areas in the southeastern half of Wisconsin that historically provided important habitat for canvasbacks during migration have experienced severe habitat degradation and, consequently, a significant decline in canvasback use. Habitat loss throughout the Upper Midwest led to large congregations of canvasbacks on the last remaining quality habitats along the Upper Mississippi River (UMR). Due to potential threats from disease, toxic spills, and habitat degradation on the UMR, the long-term health of the eastern population may depend on restoration of alternative staging habitats.

Wisconsin's historic importance to migrating canvasbacks is a compelling reason to adopt a leadership role in habitat restoration efforts in the Upper Midwest. This report presents a plan for this restoration. The recommended goal for habitat restoration is to redistribute about 20% of the annual canvasback use-days from Pools 7-9 of the UMR to the southeastern half of Wisconsin. Achieving this goal requires accommodating a total of 625,000 canvasback use-days annually through provision of 240 ha of wildcelery, 180 ha of sago pondweed, or 1,815 ha of macrobenthos beds on each of 3 sites in southeastern Wisconsin. Lake Poygan, with about 335 ha of wildcelery, already meets this requirement for 1 of the 3 sites; thus adequate food resources need development at only 2 additional sites.

Sites offering the most potential for intensive research, management, and restoration, exclusive of the UMR, include Lakes Poygan, Winneconne, Butte des Morts, Koshkonong, Puckaway, and Beaver Dam Lake. These large, shallow lakes typify canvasback staging habitat by providing large littoral areas capable of supporting relatively dense beds of wildcelery, sago pondweed, and macrobenthos and by providing large open-water areas affording some refuge from disturbance. Of these study sites, only Lake Poygan currently supports more than 10-20 ha of moderately dense wildcelery or sago pondweed. To attain Wisconsin's goal of accommodating 625,000 use-days annually in the southeastern half of the state, adequate food resources must be re-established at each of 2 sites, and the existing 335 ha of wildcelery in Lake Poygan must be maintained. Of 15 sites censused during 1985-90, Lake Poygan typically attracted the most canvasbacks during spring and fall (average peak counts of 3,300 and 700, respectively) and accounted for an average of 30,000 and 9,500 use-days during spring and fall, respectively. However, boating disturbance may be limiting canvasback use of this site.

The proportion of use-days provided by macrobenthos populations is unknown but is suspected to be small for Lakes Poygan, Winneconne, Butte des Morts, and Puckaway. High use of Lake Koshkonong and Beaver Dam Lake by staging ruddy ducks and lesser scaup suggests that these lakes support moderate to high populations of macrobenthos. Furthermore, boating disturbance may limit canvasback use of some sites and may thus need regulation through lake-use restrictions. Relatively frequent boating disturbance has been documented for Lake Poygan, and frequent disturbance is suspected for Lakes Koshkonong and Puckaway.

Reviews of literature and DNR file data demonstrated that data were inadequate for developing specific management strategies for habitat restoration and that considerable research was required first. In particular, there was a lack of information on canvasback staging populations, energy requirements, habitat status, factors limiting habitat quality and their sources, and the effectiveness of potential restoration techniques as applied to large, shallow lakes. These informational needs are addressed by the research strategy developed in this report. A Bureau of Research study on canvasback staging population and habitat status is currently addressing several of the components of this strategy by (1) determining canvasback staging populations on 15 sites in the southeastern half of Wisconsin; (2) determining abundance of wildcelery and sago pondweed, water clarity, and components of turbidity on the 6 study sites described in this report; (3) determining macrobenthos abundance in diving duck use-areas for Lakes Poygan, Winneconne, and Butte des Morts; (4) determining the extent and impact of disturbance to canvasbacks on Lake Poygan; and (5) evaluating diving duck, macrophyte, and water quality responses to an eradication project for undesirable fish on Beaver Dam Lake and a proposed large-scale breakwater project on Lake Butte des Morts. Due to budget constraints, this study has been unable to undertake the following research efforts: completely assessing present habitat quality by determining the abundance of macrobenthos and the extent of disturbance for Lakes Koshkonong, Puckaway, and Beaver Dam; thoroughly assessing the factors that limit aquatic macrophytes and macrobenthos, their sources, and their interrelationships for all the study lakes; and evaluating most of the proposed restoration techniques.

The factors limiting the abundance of foods for canvasbacks in complex shallow lake systems typically have lake- or watershed-wide causes and impacts, and the management goals for wildlife, fish, and water resources are interrelated and often overlapping. Therefore, the information and strategies provided in this report and Appendix A, below, provide guidelines for developing and refining research and management programs for these sites based on an ecosystem approach.

ADDENDUM. Recent Decline in Canvasback Food Resources on the Upper Mississippi River

This plan was originally developed because of deterioration of most migrational staging habitats in the Upper Midwest, which led to large congregations of canvasbacks on the UMR during the 1970s and early 1980s. However, in 1988-89, most of the wildcelery and macrobenthos disappeared from many of the UMR pools. Wildcelery continued to remain at low levels or to decline further in Pools 5, 7-9, and 11 during summer 1990 (C. Korschgen, pers. comm.). Degradation of these last quality habitats on the UMR could threaten canvasback survival during migration and wintering and could disrupt migration patterns to traditional wintering areas.

Furthermore, 2 plausible hypotheses accounting for the dramatic macrophyte and macrobenthos declines on the UMR in 1988-89 demonstrate the need for a multidisciplinary, ecosystem approach to effectively manage large, shallow lakes, founded on a strong informational base. According to the first hypothesis (J. Lennartson and C. Korschgen, U.S. Fish and Wildl. Serv., and J. Wetzel, Wis. Dep. Nat. Resour., to a general distribution list, in letter 3 October 1989), drought conditions and near-record low flows during 1988 led to high water temperatures and high concentrations of nutrients from normal discharges of municipal treatment plant effluent and from sediments. The resulting dense epiphyton and phytoplankton populations in late-summer shaded and smothered wildcelery, severely stressing plants during the winter bud formation stage. Plants surviving these harsh conditions apparently either did not produce winter buds or produced small, weakened winter buds with relatively low viability. Turbid water conditions persisted in spring 1989, likely due to high phytoplankton populations and wave resuspension of sediments, which further stressed the few remaining macrophytes. Decline and decomposition of macrophytes and the dense algal populations in late summer and early fall 1988, combined with high water temperatures, created a high BOD that produced extremely low DO concentrations at the sediment surface. High mortality of macrobenthos ensued.

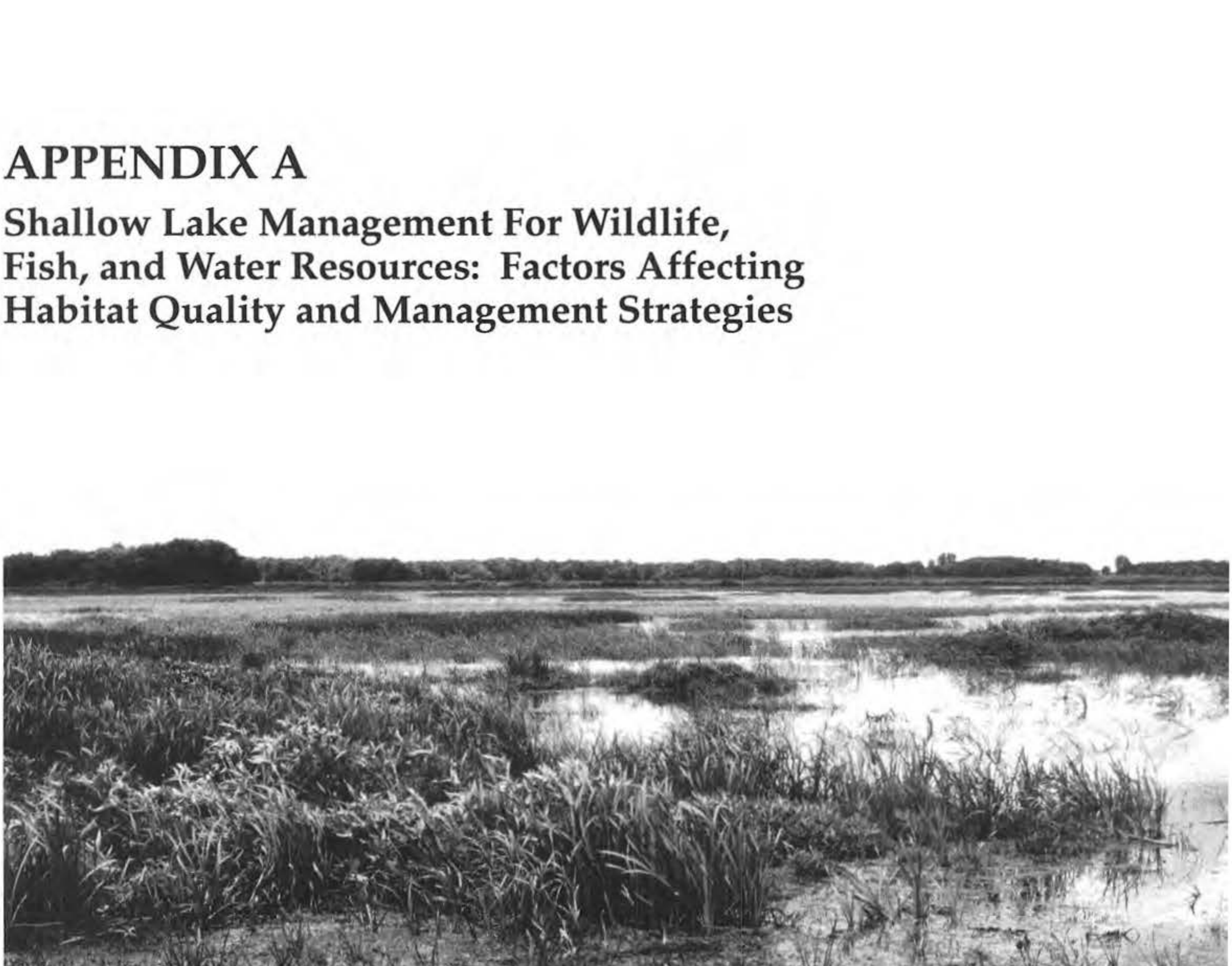
In the second, more recently developed hypothesis (J. W. Barko to R. Kahl, in letter 26 July 1991), high light availability from decreased sediment loads due to low flows and high water temperatures overstimulated wildcelery shoot and leaf growth, not phytoplankton and epiphyton growth. The altered phenology and physiology of wildcelery resulted in the shunting of most energy into leaves and shoots instead of roots and overwintering buds, thus causing a major decline in reproductive output.

These explanatory scenarios were developed primarily from observational inferences supported by little quantitative data. The suggested causes and mechanisms have not been demonstrated for pools of the UMR, and they have not been fully documented for any other large lake ecosystem. Further, factors and processes governing water quality and aquatic macrophyte re-establishment following a catastrophic event such as this are largely unknown for large, shallow lake ecosystems.

This series of events on the UMR reinforces the need for Wisconsin to accelerate its research program to quickly provide the information necessary for developing restoration strategies for canvasback staging habitat. Furthermore, Wisconsin's restoration goals must now be expanded to include the UMR. Management goals should accommodate a substantially higher staging population of canvasbacks across Wisconsin. Perhaps the new goal for all of Wisconsin, including the UMR, should support 1.25 million use-days annually, or an additional 625,000 use-days above the original goal. This requires re-establishing an additional 720 ha of wildcelery, 540 ha of sago pondweed, or 5,440 ha of relatively dense macrobenthos beds, preferably distributed among at least 3 pools of the UMR where research and habitat restoration projects have already been initiated. This habitat restoration effort for the UMR should involve cooperative projects implemented by the Wisconsin, Iowa, and Minnesota DNRs and the FWS.

APPENDIX A

Shallow Lake Management For Wildlife, Fish, and Water Resources: Factors Affecting Habitat Quality and Management Strategies



Large, shallow lakes are complex ecosystems. When healthy, these lakes support abundant and diverse populations of aquatic macrophytes, fish, and wildlife (photo by the author).

INTRODUCTION

This appendix describes factors that negatively affect communities of aquatic macrophytes, macroinvertebrates, fish, and wildlife in large, shallow lake ecosystems. These limiting factors often interact in an intricate web of interrelationships with cascading effects, in which the negative impacts on one population typically set in motion a downward spiral for many other populations in these communities (Fig. A.1). For example, excessive populations of undesirable fish (primarily carp) directly reduce populations of aquatic macrophytes, macroinvertebrates, and desirable fish through physical damage to plants, predation on macroinvertebrates, and competition with other fish for invertebrates and zooplankton (Fig. A.2). Indirectly, carp can reduce macrophytes through decreased light availability from increased turbidity and sedimentation and epiphytic algae on plant surfaces. Turbidity, sedimentation, and epiphytic algae can directly alter macroinvertebrate and desirable fish populations and can indirectly affect these populations through declining macrophyte populations. These changes then favor survival of carp, leading to greater imbalances and a spiraling downward chain-reaction for macrophyte, macroinvertebrate, desirable fish, and wildlife populations.

As suggested in the discussion on carp, above, factors that limit the abundance of aquatic macrophytes tend to exert the greatest influence on the entire system, since the abundance of macrophytes directly and indirectly affects populations of macroinvertebrates, fish, and wildlife. Aquatic macrophytes provide habitat during some phase of the life cycle for many species of macroinvertebrates, fish, and wildlife occurring in shallow lakes. Factors that primarily limit the abundance of aquatic macrophytes will secondarily limit the abundance of many macroinvertebrates, and many species of fish and wildlife depend on macrophytes and macroinvertebrates as a food base. Thus the health of macrophyte and macroinvertebrate populations will largely determine the health of many fish and wildlife populations in shallow lake systems.

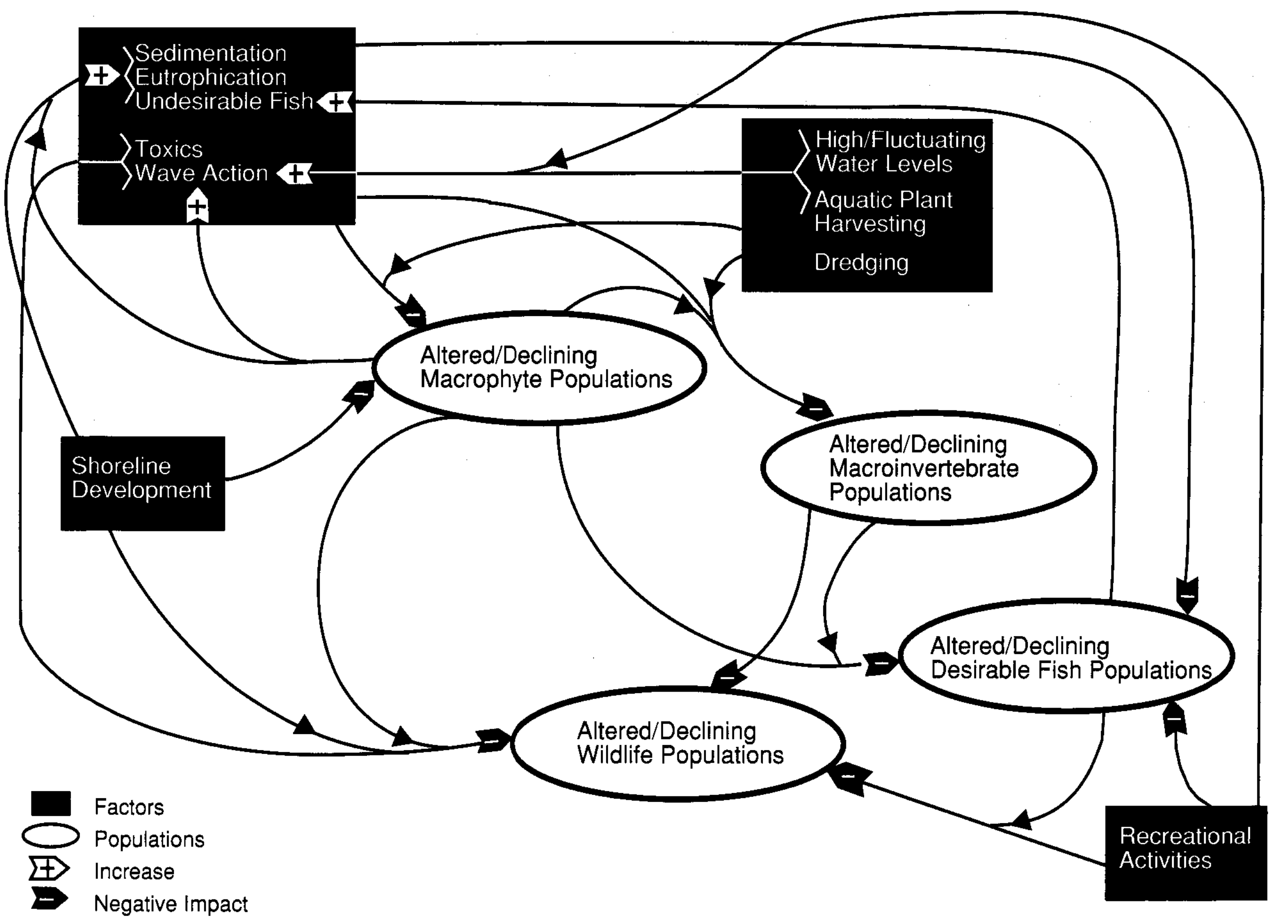


Figure A.1. *The dynamics of ecosystem response: factors described in Appendix A that affect populations of aquatic macrophytes, macroinvertebrates, wildlife, and desirable fish in large, shallow lakes.*

Many factors interact in a complex manner to control the abundance and distribution of aquatic macrophytes in shallow lakes and littoral zones (Tables A.1, A.2). The most important of these for submerged macrophytes is the availability of light to photosynthetic tissues. Light availability is influenced by sedimentation from soil and shoreline erosion, increased phytoplankton and epiphyton populations associated with eutrophication, and resuspension of bottom sediments and nutrients by undesirable fish and wave action (Fig. A.1). Other important factors limiting all aquatic macrophytes include sediment composition, high and fluctuating water levels, physical disruption by undesirable fish, waves, boats, aquatic macrophyte harvesting and control activities, and toxic pollutants. Many of these complex interrelationships for limiting factors are outlined below.

The effects of factors primarily impacting macrophytes and macroinvertebrates are emphasized in this appendix, and the obvious secondary effects on fish and wildlife are, in many instances, assumed. Several management strategies for alleviating or mitigating each of these factors are then described and evaluated. Because the re-establishment of aquatic macrophytes likely will be a key element in most restoration strategies, a section on re-establishment techniques is included in the management strategies. Finally, an example of a comprehensive management strategy for a large, shallow lake ecosystem is outlined. This material is intended to provide a basis for discussion of management strategies. To simplify presentation, references are not included here, but a bibliography is provided at the end of this appendix.

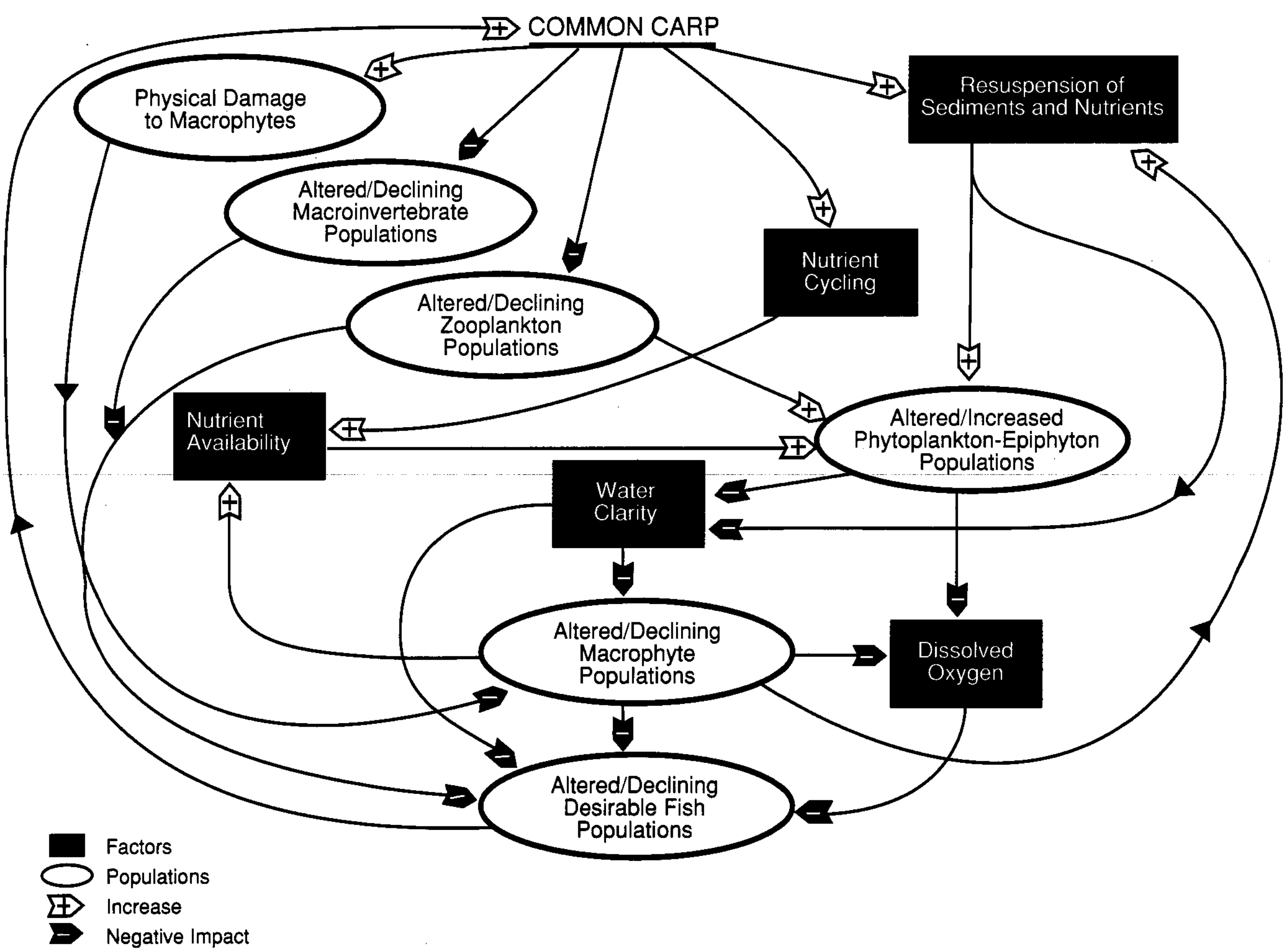


Figure A.2. *Potential ecological impacts of carp on wetland ecosystems.*

Table A.1. *Ecological requirements of 2 important submerged macrophytes that provide food for diving ducks.*[*]

Ecological Characteristic	Requirements of Submerged Macrophytes: Wildcelery	Sago Pondweed
Bottom sediments	optimum: silty sand, but tolerant of most substrates	optimum: sand with some silt or organic content, but tolerant of most substrates
Water depth[**]	optimum: 1.0-5.0 m range: 0.3-7.0 m	optimum: 0.3-3.0 m range: 0.05-11.5 m
Water level fluctuation	stable water levels	semi-stable to stable water levels in turbid water
Flow	optimum sites have some flow	tolerant of moderate flow
Wave action	adapted to withstand wave action and ice scour	contradictory information (very tolerant to relatively intolerant)
Water clarity	tolerant of relatively high turbidity and low light intensity; lower limit of photic zone is about 5-10% of surface light (range: 1-10%; contradictory information)	tolerant of relatively high turbidity (but apparently less tolerant than wildcelery); lower limit of photic zone is probably about 5-10% of surface light (range: 2.5-16.0%)
Alkalinity	moderately intolerant of high alkalinity; range: 10-338 ppm	tolerant of high alkalinity; range: 39-455 ppm
Salinity	intolerant of high salinity; range: < 10,000 ppm, mostly < 5,000 ppm (contradictory information possibly from effects of other environmental factors)	tolerant of moderate salinity; optimum: < 7,000 ppm; range: < 35,783 ppm (contradictory information)
Sulfate	range: < 318 ppm	optimum: 1,000-15,000 ppm range: < 53,000
pH	optimum: 6.8-7.0 range: 5.5-10.2	optimum: 7.0-9.0 range: 6.3-10.7
Water temperature	optimum: 20-36 C; winter bud growth initiated at 10-14 C	optimum: 23-30 C; tuber growth initiated at 10.0-12.3 C
Reproduction	perennial; primarily vegetative reproduction from winter buds, except in near-optimum conditions	perennial; primarily vegetative reproduction from tubers, except in near-optimum conditions
Habitat change	relatively tolerant of ecosystem change	very tolerant of ecosystem change

[*] See Ecological Requirements of Selected Aquatic Macrophytes in bibliography for references.
[**] Primarily determined by water quality.

Table A.2. *Ecological requirements of emergent macrophytes that provide wave attenuation.*[*]

Ecological Characteristic	Requirements of Emergent Macrophytes: Wildrice	Common Reed	Hard-stemmed Bulrush
Bottom sediments	optimum: silty organic soils, but tolerant of most substrates	optimum: sandy organic soils, but tolerant of most substrates	optimum: hard bottom, especially sand
Water depth	optimum: 8-110 cm range: 8-137 cm	optimum: < 100 cm range: < 200 cm in temperate zone	optimum: 30-90 cm range: < 150 cm
Water level fluctuation	intolerant of fluctuations > 15 cm, especially during floating leaf stage	—[**]	—
Flow	optimum sites have some flow	—	—
Wave action	moderately tolerant	contradictory information (but very tolerant in the Winnebago Pool Lakes)	very tolerant
Water clarity	photic zone depth of 1% surface light is adequate for seedling to reach the floating-leaf stage	—	—
Alkalinity	optimum: 40-200 ppm range: 5-364 ppm	range: 0.6-363 ppm	median: 122.5 ppm range: 17-273 ppm
Salinity	—	relatively tolerant of moderate salinity	—
Sulfate	optimum: < 10 ppm range: 3-282 ppm, but seldom > 50 ppm	range: 0.5-396.0 ppm	median: 19.8 ppm range: < 1,296 ppm
Iron	relatively high iron concentrations required	—	—
pH	median: 8.1 range: 6.8-8.8	optimum: 5.5-7.5 range: 3.6-9.0	median: 8.3 range: 7.2-9.1
Water temperature	seed germination at 10-15 C	rhizome growth initiated at 10-15 C	rhizome growth initiated at 10-15 C
Reproduction	annual; reproduction solely from seed	perennial; mostly vegetative reproduction from rhizomes; exposed sediment required for seed germination	perennial; mostly vegetative reproduction from rhizomes; exposed sediment required for seed germination

[*] See Ecological Requirements of Selected Aquatic Macrophytes in bibliography for references.
[**] No information available.

FACTORS CONTRIBUTING TO DECLINING FISH AND WILDLIFE HABITAT QUALITY IN SHALLOW LAKES

Sedimentation

Sources

1. Nonpoint pollution from erosion of agricultural lands, land development and construction, and urban stormwater runoff.
2. Point source pollution from industrial wastes.
3. Waves.
4. Undesirable fish.

Effects on Aquatic Macrophytes

1. Increased turbidity, which limits light penetration—and thus the maximum depth colonized by submerged macrophytes—and which disrupts phytoplankton-zooplankton community dynamics by interfering with zooplankton grazing of phytoplankton, resulting in increased phytoplankton populations that further increase turbidity.
2. Sedimentation on plant surfaces, which interferes with photosynthetic processes and respiration.
3. Deposition on the lake bottom of fine, unstable sediments that are readily resuspended by wave action and are unsuitable substrate for certain aquatic macrophyte species.
4. Altered habitat conditions that may lead to a less diverse plant community favoring undesirable plant species (e.g., Eurasian watermilfoil, curly-leaf pondweed, and purple loosestrife).
5. Habitat changes harmful to predator fish but favorable to undesirable fish, which result in greater undesirable fish populations that increase stress on and destruction of aquatic macrophyte communities.

Effects on Macroinvertebrates

1. Interference with feeding activities and respiration.
2. Mortality of eggs and young.
3. Reduction of host fish population abundance and diversity for species of clams with a glochidial stage, many of which are host-specific.
4. Loss of aquatic macrophytes and thus habitat and food for gastropods and other macroinvertebrates.
5. Alteration of substrates to increasingly unstable, soft substrates that are unsuitable for many species.

Effects on Fish and Wildlife

1. Reduced visibility and foraging efficiency of sight feeders.
2. Disruption of courtship and spawning behavior in some species due to lack of visibility.
3. Reduced productivity through decreased egg and larval survival due to resorption of eggs during turbid conditions in some species and smothering of eggs.
4. Lower survival and productivity resulting from reduced growth rates and greater susceptibility to disease due to stress and interference with respiration.
5. Possible negative impact on planktivorous species due to altered zooplankton community.
6. Possible negative impact on piscivorous species due to altered fish community.
7. Reduced predator fish populations, which allow unchecked growth of undesirable fish populations, resulting in further decreased water clarity and populations of aquatic macrophytes, zooplankton, macroinvertebrates, and desirable fish.

Eutrophication

Sources

1. Nonpoint pollution from agricultural runoff, urban stormwater runoff, and septic tank seepage.
2. Point source pollution from municipal effluents from wastewater treatment plants and industrial effluents.
3. Internal loading from bottom sediments through biological, chemical, and physical mechanisms, including undesirable fish, benthos, detritivores, aquatic macrophytes, diffusion, oxidation-reduction changes, and waves.

Effects on Aquatic Macrophytes

1. Increased phytoplankton populations, which reduce light penetration and increase turbidity.
2. Increased periphyton and epiphyton populations (including filamentous algae) on and around plant surfaces, which interfere with photosynthesis and respiration and can collapse plant stems.
3. Disruption of a balanced phytoplankton-zooplankton food chain, which leads to greater populations of less desirable blue-green algae (further decreasing light availability) and variable populations of smaller, less desirable zooplankton species.
4. Decreased DO resulting from decomposition following crashes of dense phytoplankton populations.
5. Possible development of dense, nearly monotypic plant communities resulting from altered habitat conditions favoring undesirable species.

Effects on Macroinvertebrates

1. Loss of aquatic macrophytes, thus food and habitat.
2. Depletion of oxygen at or near bottom sediments, especially during periods of stratification, from decomposition of phytoplankton and macrophytes.
3. Introduction and formation of toxics, such as ammonia N (which increases sensitivity to low oxygen levels and other toxics).
4. Reduction of host fish populations for glochidia.
5. Increase of planktonic foods (beneficial at moderate levels).

Effects on Fish and Wildlife

(See also Effects of Sedimentation, above.)

1. Increased turbidity, decreased macrophytes and macroinvertebrates, and increased undesirable fish populations, which negatively affect fish and wildlife communities.
2. Altered phytoplankton-zooplankton and macroinvertebrate communities, which may negatively impact planktivorous species (especially those depending on larger zooplankton as a food base) and "invertivorous" species.
3. Stress to fish and amphibian populations from temporarily low DO (due to decomposition of excessive phytoplankton populations) and from formation of toxics such as ammonia N.
4. Possible negative impact on piscivorous species, due to altered fish community.
5. Increased epiphytic filamentous algal populations, which may cover egg-laying substrates, making them unsuitable or unacceptable.

Undesirable Fish

(primarily carp, but also freshwater drum, bullheads, and other species that are undesirable at high population densities)

Sources

1. Reduction of predator fish populations, which allows unchecked growth of undesirable fish.
2. Habitat changes that favor undesirable fish species.

Effects on Aquatic Macrophytes

(See Fig. A.2.)

1. Resuspension of bottom sediments and nutrients from spawning and feeding activities, which limits light penetration.
2. Uprooting of macrophytes and consequent exposure of unstable sediments.
3. Internal nutrient loading through conversion and recycling of nutrients.
4. Reduced zooplankton populations, due to predation by young carp and subsequent release of phytoplankton populations from the grazing pressure of larger zooplankton.
5. Reduced DO levels, due to decomposition of increased phytoplankton populations and destruction of aquatic macrophytes.

Effects on Macroinvertebrates

1. Resuspension of sediments and nutrient loading.
2. Reduction of macroinvertebrate populations from direct predation.
3. Reduction of food and habitat, through decimation of aquatic macrophytes.
4. Reduced DO levels, due to decomposition of increased phytoplankton populations and destruction of aquatic macrophytes.

Effects on Fish and Wildlife

1. Negative effects on fish and wildlife communities from increased turbidity, reduced aquatic macrophyte and macroinvertebrate communities, reduced DO, and altered phytoplankton-zooplankton communities.
2. Competition for zooplankton and macroinvertebrate foods by expanding undesirable fish populations.
3. Spiraling negative impact on desirable fish populations, water quality, and aquatic macrophytes, due to loss of aquatic macrophytes, which provide cover for larval and juvenile fish and substrate for eggs and invertebrates, thus further reducing predator fish populations and allowing greater expansion of undesirable fish populations.

Wave Action

Sources

1. Strong winds.
2. Boating.
3. Absence of attenuating structures.

Effects on Aquatic Macrophytes

1. Resuspension of bottom sediments and nutrients, which restricts light availability.
2. Sedimentation and lodging of organic material and filamentous algae on plant surfaces, which interfere with photosynthesis and respiration and collapse plant stems.
3. Abrasion and physical stress on plants.
4. Erosion of shoreline and marsh vegetation from waves and ice shoves, which further exposes unstable sediments for resuspension.
5. Erosion of unstable sediments in littoral zones, which creates deeper areas less favorable for aquatic macrophyte growth.
6. Prevention of re-establishment of aquatic macrophytes, resulting from damaged and uprooted seedlings and young plants and from shifting, unstable substrate.

Effects on Macroinvertebrates

1. Sedimentation on invertebrates.
2. Reduction in aquatic macrophytes, which provide habitat and food for macroinvertebrates.
3. Alteration of substrates and water depths.
4. Increased movement of planktonic foods for sedentary molluscs.
5. Disruption of temporary stratification (may be beneficial).

Effects on Fish and Wildlife

(See also Effects of Sedimentation and Eutrophication, above.)

1. Increased turbidity and sedimentation, decreased macrophyte and macroinvertebrate populations, and increased undesirable fish populations.
2. Disturbance from boating activity (see Effects of Recreational Activities, below).
3. Difficult conditions for feeding, resting, spawning, breeding, etc., due to wave energies.
4. Destruction of nests, egg masses, and protective structures such as muskrat lodges.

High and Fluctuating Water Levels

Sources

1. Inadequate water level control capabilities.
2. Conflicting water level management goals for transportation, recreational boaters, shoreline property owners, power generation, municipal and industrial needs, and fish and wildlife habitat.

Effects on Aquatic Macrophytes and Macroinvertebrates

1. Excessive water levels in adjacent marshes, which create floating mats of emergent macrophytes that are susceptible to disintegration and loss from wave and ice action.
2. Larger areas of open water and greater wind-wave action with high water levels.
3. Constriction of the littoral zone, with high water levels increasing the distance required for adequate light penetration to existing submerged macrophytes.
4. Rising water levels in spring prior to ice-out, which causes ice damage to vegetation, bottom sediments, shorelines, and marsh edges.
5. Excessive drawdown during winter, which causes frost damage to aquatic macrophytes and macroinvertebrates.
6. Stress and mortality for emergent and floating-leaved macrophytes, due to submersion of specialized photosynthetic tissue that requires exposure to air, forced elongation of stems beyond a tolerance level for efficient gas and nutrient exchange between root systems and primary photosynthetic tissue, and depending on timing and magnitude of fluctuations, uprooting (especially of wildrice if water levels rise rapidly during the floating leaf stage in June and early July).

Effects on Fish and Wildlife

1. Inundation/destruction of nesting substrates and nests of water birds from high or fluctuating water levels in spring and early summer.
2. Inundation/destruction of muskrat lodges with high and fluctuating water levels; exposure of muskrat lodges and food supplies in adjacent marsh habitat resulting from drawdowns in fall prior to ice formation.
3. Isolation of shallow bays and channels, caused by ice from excessive winter drawdowns, which can trap and kill fish.
4. Lack of access to spawning marshes, due to maintenance of low water levels during early spring.
5. Freezing of marsh sediments from excessive winter drawdown, which may kill hibernating herptiles.

Overharvest of Aquatic Macrophytes

Sources

1. Collection of seeds and propagules by plant nurseries for stock and sale to improve other fish and wildlife habitats and to stabilize bottom sediments and shorelines elsewhere.
2. Lake associations, shoreline property owners, and resort owners removing or controlling aquatic "weeds" with herbicides and mechanical methods to improve aquatic recreational opportunities.

Effects on Aquatic Macrophytes and Macroinvertebrates

(See also Effects of Toxic Pollutants, below.)

1. Direct removal or death of plants and macroinvertebrates.
2. Exposure of unstable sediments.
3. Resuspension of sediments.

Effects on Fish and Wildlife

(See also Effects of Toxic Pollutants, below.)

1. Direct removal of fish and wildlife from mechanical harvesting.
2. Indirect reduction in populations due to habitat and macroinvertebrate loss.
3. Disturbance to fish and wildlife.

Toxic Pollutants

Sources

1. Pesticides from agricultural activities and aquatic macrophyte control.
2. Industrial pollution, both from point sources and from airborne toxins.

Effects on Aquatic Macrophytes and Macroinvertebrates

1. Direct loss or long-term stress to vegetation and invertebrates.
2. Disruption of phytoplankton-zooplankton community dynamics by decreasing zooplankton populations or grazing efficiency.

Effects on Fish and Wildlife

1. Direct mortality or long-term stress and lower survival/productivity.
2. Uptake and bioconcentration by macroinvertebrates and macrophytes, with potentially indirect effects on consumers, including wildlife, fish, and humans.

Dredging

Sources

1. Maintenance/creation of boating channels, lakeshore developments, and marinas.
2. Lake restoration projects involving removal of nutrient-enriched sediments or lake deepening.

Effects on Aquatic Macrophytes and Macroinvertebrates

1. Direct removal of macrophytes and invertebrates and, often, destruction of adjacent wetlands.
2. Burial.

3. Sedimentation on plants and invertebrates.
4. Removal of nutrient-rich bottom sediments, which reduces internal loading (potential long-term benefits in highly eutrophic systems).

Effects on Fish and Wildlife

1. Disturbance from dredging activities and, indirectly, from greater recreational activity associated with improved navigation channels and more developed shoreline and marinas.
2. Improved survival of desirable fish species from lake restoration projects that remove nutrients and create deeper water areas, which enhance overwinter survival.
3. Direct removal of fish and herptiles.

Recreational Activities

(See also Effects of Sedimentation and Wave Action, above.)

Sources

1. Recreational boating.
2. Hunting and fishing.

Effects on Aquatic Macrophytes and Macroinvertebrates

1. Direct physical damage to macrophytes from boat propellers.
2. Resuspension of sediments and nutrients from boat wakes.
3. Shoreline erosion from boat wakes.

Effects on Fish and Wildlife

1. Greater energy demand, due to evasion/avoidance of disturbance.
2. Less time for feeding and possibly inadequate access to food resources, due to disturbance.
3. Stress and suboptimal body condition, which potentially decreases survival and reproduction.
4. Interference with breeding or spawning activities and inadequate access to breeding, nesting, or spawning habitat.
5. Increased turbidity from boat wakes, which interferes with feeding, courtship, spawning, etc.
6. Ultimately, diminished use of an area.

Shoreline Development

Effects on Shallow Lake Ecosystems

1. Reduction in lake management flexibility.
2. Filling and loss of wetlands, which provide both a natural filtration system that removes suspended solids and nutrients and also important fish and wildlife habitat.
3. Reduction in shoreline vegetation, which results in less filtering of sediments and nutrients from development, landscaping activities, pet wastes, and septic system failure.
4. Greater shoreline erosion, due to reduction of shoreline and nearshore vegetation following "weed" removal.
5. Greater disturbance to fish and wildlife, due to shoreline activities and increased boating.

MANAGEMENT STRATEGIES

Nonpoint Pollution Abatement

Strategies

1. **Watershed master plan** utilizing the "Best Management Practices" approach to reduce or eliminate nonpoint pollution from barnyard runoff; manure storage and spreading practices; erosion from cropland, riparian zones, and construction sites; urban stormwater runoff; and failing septic systems.
2. **Change in government policy** including legislation linking soil and water conservation to agricultural programs, land-use planning and zoning to control development, and stricter building codes and/or subdivision regulations that incorporate measures to control soil erosion.
3. **Urban stormwater diversion.**
4. **Biological treatment and filtering** of urban runoff and wastewater and agricultural runoff using wetlands, especially through wetland preservation and restoration programs.
5. **Sediment traps.**

Potential Benefits

1. Improved water clarity and quality.
2. Increased aesthetic and recreational value of water resources.
3. Better land management practices and conservation of soil and water resources.
4. Increased quantity and quality of aquatic and upland habitat.
5. Decreased cost of drinking water treatment.
6. Reduced bacterial and toxic loadings to surface and groundwater from control of soil erosion and animal wastes.
7. Decreased dredging maintenance of navigation channels.

Evaluation of Strategies

1. **Watershed master plan.** This strategy addresses sources of the problem, not just symptoms, and has potential for the greatest benefits and long-term results. Implementation of Best Management Practices will reduce soil erosion and agricultural and stormwater runoff, all of which contribute to eutrophication. A

watershed master plan incorporates consideration of all other lake and watershed restoration techniques, selecting those most appropriate and cost effective, based on knowledge of the entire watershed function. On the negative side, this strategy requires considerable cooperation and agreement among agencies and the public. It requires assembly and/or collection of numerous baseline data, including soil types, topography, land use, land management practices, watershed hydrology, weather patterns, water quality, and sources of sedimentation and nutrient loading. The only effective method of managing, processing, and integrating all of these data is through a Geographic Information System. Successful implementation depends both on convincing many landowners to make changes in basic land practices and on providing economic incentives for improving these practices.

2. **Change government policy** (including land-use planning and agricultural policy). This strategy focuses on a major cause of the problem—the existence of various government programs and regulations that in many instances encourage poor land management practices. However, transforming government policy can be a very slow process, impeded by considerable resistance from special interest groups.
3. **Urban stormwater diversion.** This strategy could be very effective if designed properly and combined with other measures, such as building codes and subdivision regulations for controlling runoff; porous pavement; frequent street sweeping; and public education on the impacts of improper lawn fertilization techniques and municipal leaf-litter removal. Cost would be greatly reduced if implementation of this alternative were incorporated into planned road and sewer maintenance and improvements.
4. **Biological wastewater treatment using wetlands.** This strategy focuses public awareness on the value of wetlands, thus encouraging wetland preservation. Combining this approach with a strong wetland protection and restoration program would greatly enhance the effectiveness and scope of benefits. On the negative side, wetlands can only accommodate relatively small inflows and must be strategically located to intercept runoff and wastewater outflows. This strategy has had inconsistent net annual results, although the technique has proven effective in reducing loadings of nutrients and suspended solids in several small watersheds. Long-term effects on wetland ecosystems are unknown, but aging of the wetlands is probably accelerated.
5. **Sediment traps.** This strategy is potentially very effective for small inflows but has several negative features. First, it remedies a symptom, not the problem. It requires monitoring both for proper functioning and for periodic dredging, it impedes boat and fish movements on larger inlets, it is not feasible for very large inlets, and it provides inadequate control of nutrients.

Point Source Pollution Abatement

Strategies

1. **Stricter environmental quality standards** coupled with better compliance through education, monitoring, enforcement, and higher penalties.
2. **Research and development of techniques** to remove toxics and organic and inorganic solids from discharges.
3. **Change in manufacturing processes** to eliminate production of toxic wastes.

Potential Benefits

1. Improved water quality and clarity with increased aesthetic and recreational value.
2. Reduced cost of drinking water treatment and eventual clean-up of contaminated areas.
3. Reduced health risks to the public and to fish and wildlife resources.
4. Increased DO and improved survival of desirable fish and aquatic invertebrates.

Evaluation of Strategies

1. **Stricter standards and enforcement.** This strategy remedies the problem, not just a symptom. However, it increases cost to industry and municipalities and also increases the cost of enforcement (possibly offset partially by higher penalties). Public and government support for this alternative is needed, but may be difficult to attain.
2. **Research and development of removal techniques.** This strategy also remedies the problem, rather than a symptom. New techniques could allow greater industrial and wastewater treatment-plant discharges with lower pollution levels. The cost of prevention is typically much lower than the cost of clean-up. On the negative side, this strategy initially increases cost to industry, municipalities, and the public.
3. **Elimination of the production of toxic wastes.** This strategy remedies the problem. By developing alternative manufacturing methods that eliminate toxic wastes, both industry and the environment benefit, since industry avoids the cost of proper toxic waste disposal and/or fines. This strategy requires initial investment in research and development of alternative manufacturing practices.

Eutrophication Control

(in-lake treatments)

Strategies

1. **Control/removal of undesirable fish.**
2. **Biomanipulation** (altering the food chain).
3. **Aquatic macrophyte control/removal** in lakes with nuisance plant problems.
4. **Nutrient inactivation/precipitation.**
5. **Bottom sealing.**
6. **Dredging.**
7. **Destratification/aeration.**
8. **Dilution/flushing.**
9. **Algicides.**

Potential Benefits

1. Reduced nutrient availability, resulting in lower phytoplankton populations and fewer nuisance algal blooms.
2. Increased water clarity.

3. Reduced cost of drinking water treatment.
4. Increased desirable fish and wildlife habitat and populations.
5. Increased aesthetic and recreational value of water resources.

Evaluation of Strategies

1. **Control/removal of undesirable fish** (see also Undesirable Fish Population Control, below). This alternative removes nutrients from the system and provides potentially desirable material for agricultural fertilizer. By removing a source of internal nutrient cycling, this technique further improves water clarity. However, partial control/removal programs require annual effort, and prior research is required to clarify the mechanisms involved and magnitude of undesirable fish contribution to nutrient cycling.
2. **Biomanipulation.** For several small lakes, this technique has proven effective, especially when combined with watershed management. This concept is also currently being evaluated for several large lakes. By manipulating fish and zooplankton populations to control phytoplankton, this strategy can yield long-term improvements in water quality and fisheries. However, this strategy may not address the sources of the problem (e.g., external nutrient loading) and requires additional research. In order to alter populations of planktivorous fish to allow an increase of zooplankton populations that forage on phytoplankton, control of populations of some desirable species, such as yellow perch, may be required. Success in control of planktivorous fish by introduction of predator fish may require prior improvement in water quality and aquatic macrophyte populations. Costly, large-scale stocking of predator fish is necessary.
3. **Aquatic macrophyte control/removal.** This strategy reduces internal nutrient loading, since macrophytes can act as nutrient pumps, extracting nutrients from sediments and releasing them to the water both during the life of the plant and then during decomposition. It reduces the potential for winterkills and provides desirable material for agricultural soil enhancement. On the negative side, this strategy is mostly cosmetic, primarily providing short-term benefits to water-based recreation. Greater boating activity then increases resuspension of sediments and nutrients from wave action and increases disturbance to fish and wildlife. Removal of macrophytes exposes large areas of sediments and allows greater wave action, further increasing resuspension. Chemical control does not remove nutrients from the system; rather, it probably increases nutrient availability to phytoplankton from the death and decomposition of macrophytes. Mechanical control removes only small and insignificant amounts of nutrients in most cases. Additionally, cut stems exude nutrients, temporarily enhancing nutrient availability to phytoplankton. This technique also directly removes and destroys habitat and food for fish and wildlife and decreases detrital input, food, and cover for benthic invertebrates. Lastly, this strategy may alter species composition by favoring species that vegetatively propagate; it may lead to dominance of less desirable species such as Eurasian watermilfoil and coontail. This strategy requires annual effort, and effectiveness depends on control of nutrient loading. However, less intensive harvest strategies can be designed to favor desirable plant species and predator fish.
4. **Nutrient inactivation/precipitation** (alum-type compounds). This strategy has proven effective on numerous small lakes with benefits for as long as 9-10 years, but it is probably neither feasible nor effective in large, shallow lakes where high wave energies frequently disturb bottom sediments. Determination of safe application rates requires accurate information on sources and loading levels of phosphorus. This information may be difficult to obtain for a large, complex system. Application of these compounds may be detrimental to benthic invertebrates, but late fall applications may reduce harmful effects. Effectiveness varies with the specific situation and climatic conditions during and immediately after treatment. Major external sources of phosphorus must be controlled to reduce eutrophication. High sedimentation rates reduce effectiveness by rapidly covering the precipitated layer. This strategy may not be feasible for lakes with short water-turnover times and moderate flow. It is controversial, with unknown long-term impacts on fish and invertebrates; however, there has been no documented short-term damage with proper application rates.
5. **Bottom sealing.** This strategy has proven effective for some small lakes but probably is not feasible for large, shallow lakes due to excessive cost and difficulty in maintaining integrity of the barrier in the presence of high wave energies. It eliminates suitable habitat for plant growth and covers and destroys the benthic community.
6. **Dredging.** The effectiveness of this strategy has been demonstrated for relatively small lakes, especially in combination with measures to control external loading and nutrient inactivation treatments to further reduce internal loading. Disposal of sediments on agricultural lands could improve fertility and soil quality. Limited dredging can enhance overwinter survival of desirable fish species by creating deep-water areas. Barrier islands made with dredge spoil can also provide safe nesting habitat for many avian species, while reducing wave action. However, this strategy is not feasible over large areas due to high costs and disposal problems. Type and availability of equipment, availability of disposal and dewatering sites, and transportation distance for disposal determine cost. Disposal costs may be prohibitive if toxics are present. Considerable (but temporary) resuspension of sediments and nutrients can occur. This technique directly destroys aquatic macrophytes and benthic invertebrates. Light must penetrate to greater depths to reach aquatic macrophytes. Many toxics adhere to fine particles, which settle more slowly and are left on the surface of bottom sediments. Short-term, localized oxygen depletion can occur if highly organic sediments are resuspended and concentrated. Nutrient levels will increase, since phosphorus readily adheres to fine sediments. Further, there are potential health hazards associated with handling and disposing of contaminated sediments.
7. **Destratification/aeration.** This strategy can provide long-term benefits by temporarily limiting algal productivity, decreasing pH (which favors green algae and diatoms over blue-green algae), and possibly favoring increased survival of zooplankton, which forage on and thus control algae. However, this alternative is not applicable for shallow lakes that typically stratify only during brief calm periods. Destratification/aeration eliminates the symptoms but not the root of the problem and requires continual treatment, since nutrients are not removed from the system.

8. **Dilution/flushing.** This strategy has proven effective on small sites. Most large, shallow lakes have a source of dilution/flushing water, but this water is typically of poor quality. This strategy requires a source of cleaner water. The amount of water needed to effect noticeable improvements increases significantly with increasing lake size, especially if considerable nutrient loading occurs from sediments.
9. **Algicides.** This strategy temporarily improves water clarity and decreases the cost of drinking water treatment. However, there is no removal of nutrients and no long-term benefits. Multiple treatments are typically required annually; thus toxicants are frequently introduced. The long-term impacts on ecosystem functions are unknown.

Wave Attenuation

Strategies

1. **Artificial breakwaters and islands** (permanent and temporary).
2. **Living breakwaters** (emergent aquatic macrophytes).
3. **Artificial reefs.**
4. **Shoreline protection** (riprap, other revetments, bulkheads).

Potential Benefits

1. Improved water clarity due to reduced resuspension of sediments and nutrients (from breakwaters and islands) and reduced shoreline and marsh-edge erosion by waves and ice shoves (from shoreline protection).
2. Increased structure for fish and wildlife habitat; island construction can significantly benefit waterfowl and other waterbirds by providing secure, predator-free nesting habitat.
3. Decreased shoreline and marsh-edge erosion.
4. Increased natural growth of aquatic macrophytes and improved conditions for re-establishment through plantings.
5. Increased habitat for aquatic macrophyte colonization due to shoaling.
6. Decreased loss of critical wetland habitat.

Evaluation of Strategies

1. **Permanent breakwaters and islands.** This strategy is probably the most effective technique for long-term protection and enhancement of aquatic macrophytes from ice and wave action in large, shallow lakes. It also involves relatively low maintenance costs if properly designed. However, these structures involve high initial construction costs, they provide no flexibility for relocation or removal, and they may be prone to occasional ice damage. Preparatory studies to determine the design, placement, and impact of these structures on lake-wide currents, flows, flooding, waves, and adjacent shorelines will be costly. An Environmental Impact Statement may be required. State statutes may have to be introduced to allow placement of these structures on a lake bed. Strong opposition may arise from boaters, lakeshore property owners, and other special interest groups. Appropriate design of permanent breakwaters to allow access to marsh habitat for spawning by desirable fish species also allows access to spawning carp. Considerable research is required to evaluate designs and placement and to clarify mechanisms involved in macrophyte and water quality response to wave attenuation.
2. **Temporary breakwaters.** This strategy provides flexibility in design, placement, cost, and relocation, with relatively low initial costs. Depending on design, it provides attractive fish habitat. On the negative side, there are relatively high maintenance costs, including adequate marking with lighted buoys and posting. These structures are susceptible to ice and wave damage and may require annual removal to avoid ice damage. There is a lack of information on the effectiveness of various designs and materials for lake applications, especially for low-cost alternatives. Disposal costs can be relatively high, depending on materials and design. This alternative requires continuous annual effort; otherwise, benefits accrued during placement may be quickly lost after removal.
3. **Living breakwaters.** Once established, this strategy could require only low maintenance, or none at all, unless environmental conditions change. It provides excellent fish and wildlife habitat. In contrast to temporary structures, there is low danger to boaters; no posting or marking is required. There are no disposal costs, and the breakwaters are highly aesthetic. They sometimes create shoals, which further encourage macrophyte colonization. This strategy re-establishes vegetation, stabilizes relatively large areas of sediments, and ties up nutrients. On the negative side, successful re-establishment may require either decreased spring-summer water levels or costly construction of shallow shoal areas for planting. Furthermore, information on components such as planting techniques and site requirements is insufficient. Seed germination typically requires exposed mudflats, so this alternative probably requires more costly and difficult planting techniques for asexual propagules (e.g., tubers, rhizomes, and rootstalks). Preparation and planting costs are relatively high, and construction of reef shoal areas to create adequately shallow conditions for plant survival may be required (see Tables A.1, A.2 for ecological requirements of emergent macrophytes). Living breakwaters are susceptible to water quality problems, wave action, ice action, snowmobile damage, boating damage, and animal damage.
4. **Artificial reefs.** This strategy could provide habitat for desirable fish and macrophytes. Some shoaling may also occur, thus providing additional shallow water habitat for fish and macrophyte colonization. The potential benefits of this strategy are increased if combined with establishment of a living breakwater. Ice damage will probably be negligible if the reef is completely submersed. However, these reefs must be shallowly constructed to provide wave attenuation and colonizable habitat for macrophytes, but when shallowly submersed, an artificial reef is a dangerous, unseen obstacle to larger boats. This alternative primarily provides fish habitat, with fewer benefits for aquatic macrophytes and wildlife.
5. **Shoreline protection.** This strategy is the most effective method of reducing shoreline erosion and loss of wetlands over long periods. On the negative side, it is relatively costly and has less effect on water clarity than in-water structures. It does not allow expansion of wetlands and provides no additional habitat for colonization by aquatic macrophytes.

Water Level Stabilization

Strategy

Water level management plan designed to benefit aquatic macrophytes (requires adequate control-structure capabilities and source of water).

Potential Benefits

1. Improved conditions for aquatic macrophyte establishment and growth.
2. Improved water clarity if aquatic macrophytes increase.
3. Reduced shoreline erosion and loss of wetlands from ice and wave action.

Evaluation of Strategy

This strategy could produce system-wide improvements in fish and wildlife habitat, as well as in water quality, by encouraging aquatic macrophyte growth. Late spring and summer water levels typically need to be stabilized at lower levels to encourage colonization by submerged macrophytes over a greater area and to improve vigor and induce expansion of existing stands of perennial emergent macrophytes. Lower spring and summer water levels would also likely reduce shoreline marsh erosion. Furthermore, ice damage to shorelines and marsh edges can be reduced or eliminated by a winter drawdown and delayed water level increases until after ice-out. Magnitude of winter drawdowns must be closely monitored to avoid exposure of mudflats and to prevent ice formation in sediments, which can damage overwintering propagules of some species of aquatic macrophytes. Winter drawdowns should begin after adequate ice formation in adjacent marshes to insulate herptiles, furbearers, and food stores from exposure to freezing temperatures and predators.

This strategy is essential for maintaining increases in aquatic macrophytes gained from other management activities. On the negative side, it requires considerable discussion and input from many diverse user groups among which consensus is often difficult to achieve, and it requires the compilation of much information on the impacts of the plan on these groups. Research is required to clarify the extent and magnitude of the benefits of this technique. It would be costly to assemble the required information on, for example, hydrology, inflows, outflows, and precipitation patterns. This technique requires annual monitoring of precipitation and winter snowpack for prediction of spring runoff. It also requires frequent monitoring of water levels for quick response to fluctuations. Construction or modification of control structures requires an Environmental Impact Statement and approval by the U.S. Army Corps of Engineers.

Undesirable Fish Population Control

Strategies

1. **Complete eradication.**
2. **Spot treatment.**
3. **Biomanipulation by augmenting predator populations.**
4. **Subsidy of commercial fishery for undesirable fish.**

Potential Benefits

1. Improved water clarity and quality.
2. Increased aquatic macrophyte growth and survival.
3. Improved sport fishery through improved predator efficiency, improved fish habitat, increased desirable fish populations, and less angling interference by undesirable fish.
4. Removal of nutrients from the system.
5. Removal of a source of internal cycling of nutrients.

Evaluation of Strategies

1. **Complete eradication.** This strategy typically leads to the quickest and most dramatic improvements in water clarity, natural revegetation, and desirable fish populations. Long-term results can be achieved if this alternative is combined with other techniques such as desirable macrophyte transplants, stocking of adults of key predator species, creation of spawning habitat for predators, aeration to prevent winterkill of more susceptible predator species, and fish barriers on inlets and outlets. However, research is required to identify the ecosystem functions and processes involved in development of excessive undesirable fish populations and to evaluate ecosystem approaches to long-term control. This strategy is very costly for large water bodies with large drainage systems. It typically requires drawdown and application of a toxicant, and it results in the elimination of nontarget species. These controversial and highly visible aspects are unacceptable to many users and often lead to strong public opposition. Fish barriers are usually necessary; barriers require construction, installation, operation, and maintenance costs, and they interfere with boaters and spawning runs of desirable fish species. There are also problems associated with the disposal of dead fish. Results of eradication may be reversed or completely mitigated in a relatively short time by accidental or malicious reintroduction or by an incomplete kill.
2. **Spot treatment.** This strategy is less costly, usually receives less overall opposition than complete eradication, and is potentially as effective over the long term if it is combined with other techniques. On the negative side, piscicides have no specificity and thus also eliminate nontarget species. This strategy produces noticeable results more slowly. It requires a continued annual effort. It may not be effective in some situations, especially where ingress of undesirable fish cannot be eliminated or reduced or where spawning and feeding concentrations are erratic and difficult to isolate.
3. **Predator population augmentation.** This strategy can provide long-term control if appropriate predator species are stocked and populations can be maintained. It directly improves the fishery and is a highly visible activity with strong public support. On the negative side, water quality and habitat improvements probably are necessary before this alternative can be effective. Research is needed to identify the ecological mechanisms and responses to population manipulations and to evaluate biomanipulation techniques and benefits.
4. **Commercial fishery subsidies.** This strategy is usually noncontroversial. It has relatively little impact on nontarget species and represents a modest cost to agencies and the public. (This type of subsidy is optimally funded and administered by lake associations and districts and by local conservation groups.) Long-term control of

undesirable fish is possible, especially if the subsidy is combined with other management techniques coordinated through natural resource agencies. However, this strategy requires an annual effort, and if it is successful it results in declining returns and less marketable fish to the commercial harvester, creating greater difficulty in attracting a commercial harvester and a greater compensation cost. The annual cost is unpredictable, since it depends on the market for undesirable fish. Less control over timing, effort, and harvest levels is possible. There also are potential problems with disposal of unmarketable or contaminated fish.

Control of Aquatic Macrophyte Overharvesting

Strategies

1. **Stricter regulation and monitoring of harvesting.**
2. **Prohibition of all harvesting.**

Potential Benefits

1. Increased health and abundance of aquatic macrophyte populations (may have a negative effect where populations are too dense).
2. Improved water quality.
3. Reduced public controversy over the conflict between aquatic macrophyte restoration efforts and harvest of vegetation.

Evaluation of Strategies

1. **Stricter regulation and monitoring.** This strategy will incur less opposition than prohibition and provides flexibility in management decisions. The DNR, with input from the public, can better manage wetland and lake resources by directing aquatic macrophyte harvesting through the development of guidelines for restricting methods, locations, species, and quantities for harvesting. While costs to administer a permit and report system are high, these costs can be potentially offset by a fee. However, this strategy requires increased enforcement efforts and revision of state statutes and administrative codes. Research would be needed to assess and document harvesting impacts.
2. **Prohibition.** This strategy precludes benefits to a few individuals at the expense of habitat degradation in systems that are stressed and already depauperate of plant life. It is also the least expensive alternative. However, there will be considerable opposition from individuals who have serious nuisance plant problems and from commercial harvesters who depend on aquatic macrophyte harvesting for their livelihood. Further, this alternative would restrict the DNR's management options for wetland and lake restoration involving macrophyte transplants or control/removal of undesirable species. Complete prohibition allows no flexibility for controlling localized nuisance populations that probably would have no impact on healthy systems. This strategy requires revision of state statutes and administrative codes as well as research to justify prohibition by assessing and documenting the impacts of harvesting.

Pesticide Toxicity Reduction

Strategies

1. **Promote biological and mechanical control,** emphasizing minimum tillage and sustainable agriculture methods along with integrated lake management.
2. **Enforce proper application techniques, rates, and site selection.**
3. **Promote or require use of readily biodegradable pesticides.**
4. **Promote and implement adequate soil and water conservation** practices to reduce runoff of pesticides from croplands and lawns.

Potential Benefits

1. Decreased toxicity to nontarget organisms.
2. Reduced soil erosion and improved upland habitat from soil and water conservation practices and more discriminate use of pesticides.
3. Increased availability of invertebrate and plant foods (especially seeds) for many vertebrate species, including upland game birds, song birds, waterfowl, herptiles, and fish.
4. Greater biodiversity.
5. Reduced risk of groundwater contamination.

Evaluation of Strategies

1. **Biological and mechanical control.** This strategy requires a systems approach, which fosters awareness of biological functions of a system and the implications of various actions for the entire system. In agricultural systems, habitat diversity is improved by smaller field sizes, better soil and water conservation practices, and more diverse cropping and land use patterns. This strategy reduces or eliminates the introduction of potentially harmful pesticides and fertilizers into the environment, and it may be less costly over time. Risk to groundwater and nontarget organisms is reduced, and aquatic and terrestrial habitat and the availability of invertebrate and plant foods for fish and wildlife are improved. However, more research is required on effectiveness, profitability, and the most effective combinations of practices. Intensive farm and lake management and planning are also required. For farms, several techniques and alternatives must be incorporated with small-scale cropping patterns, frequent crop rotation, minimum tillage, and alternate and cover crops. For lakes, management and planning must incorporate small-scale aquatic macrophyte harvesting patterns tailored specifically for nuisance species and user needs, with management for desirable aquatic macrophytes. Research on biological control has lagged behind research on other control techniques.
2. **Enforcement of proper application techniques and rates.** By requiring the discriminate use of pesticides, this strategy reduces risk to nontarget organisms and groundwater and lowers pesticide costs while retaining adequate control. On the negative side, enforcement requires considerable time and money to closely monitor many individuals, especially during peak application periods; onsite inspection during or immediately after application is required. There may be strong opposition

to governmental control and oversight of their activities from agricultural communities, property owners with large lawns to maintain, golf courses, and lakeshore property owners.

3. **Biodegradable pesticides.** This strategy responds to public and natural resources agency pressure to protect groundwater by developing less toxic and quickly degradable pesticides. This reduces the risk of bio-accumulation and toxicity to nontarget species. The shorter period of effectiveness of these pesticides can be beneficial for weed control by allowing greater flexibility in choices of herbicides and post-treatment crops. On the negative side, a shorter effective life span would reduce pest control efficacy and require more frequent application.
4. **Soil and water conservation.** This strategy reduces nonpoint pollution and increases terrestrial and aquatic habitat, as well as reducing movement of pesticides into nontarget areas. However, this strategy does not remedy the source of the problem—the inappropriate and indiscriminate use of pesticides. Further, pesticides may be concentrated in small wetlands and other areas devoted to permanent cover to reduce erosion.

Reduced Disturbance to Fish and Wildlife

Strategies

1. **Inviolate (no-entry) refuges.**
2. **Fish and wildlife protection areas** prohibiting disturbance to fish and wildlife.
3. **Voluntary compliance refuges.**
4. **No-wake or nonmotorized zones.**
5. **Restricted fishing and hunting seasons or areas.**
6. **Public awareness campaigns.**

Potential Benefits

1. Increased fish and wildlife use in protected areas.
2. Improved health, survival, and productivity of fish and wildlife, especially if feeding, breeding, and spawning areas are within protected areas.

Evaluation of Strategies

1. **Inviolate refuges.** This strategy is the most effective one because it eliminates all boating traffic, and it is the most enforceable one because it eliminates subjective interpretation of what constitutes disturbance or protection. However, it is presently unconstitutional to restrict access to navigable waters in Wisconsin; thus a constitutional amendment would be required. This option requires close attention by managers to ensure that the refuge is well-marked and in effect only when significant numbers of the target species are present. This strategy is the most controversial one to the widest range of users, especially if it restricts access when few or none of the target species are present.
2. **Fish and wildlife protection areas.** This strategy clearly states to the public the intention of the refuge, and it should restrict access only when the target species are present. This strategy is within DNR purview by state statute, and it would probably be effective in deterring most disturbance. However, this strategy may be unenforceable in court, depending on the subjective interpretation both of disturbance to fish and wildlife and of criminal intent of violators. Restrictive use is controversial to most users not directly interested in increased fish and wildlife populations. It also requires considerable attention and maintenance by DNR managers to ensure that the refuge is in effect and well-marked during the approximate time of fish and wildlife use.
3. **Voluntary compliance refuges.** This strategy is likely acceptable to all users and probably deters some disturbance. It requires neither legal action nor legal interpretation. On the negative side, this probably is the least effective measure because it carries no enforcement power. This strategy also requires considerable DNR management time to post announcements and publicize the effort for only a moderate level of effectiveness.
4. **No-wake or nonmotorized zones.** This strategy deters most boat traffic through the area, since most boaters probably would circumvent the area rather than slowly boating through it. This option is less controversial to many users, since entry is not restricted and the greatest inconvenience is in circumventing the area or slowly traveling through it. (Impacts on waterfowl are lessened by slower boat traffic; canvasback flushing probability and flushing distance from boats were directly related to boat speed on Lake Poygan.) On the negative side, this strategy is moderately controversial to some users. It must be enacted by local governments and thus requires the difficult process of obtaining local consensus and agreement on the appropriate responsibility for posting, maintaining, and enforcing protection. There is also limited enforcement potential due to the subjective interpretation of what constitutes a boat wake.
5. **Fishing and hunting restrictions.** This strategy reduces disturbance by the most frequent users of most sites during spring and fall. Since violation can be legally interpreted objectively, this option is very enforceable, and it is within DNR purview by state statute. It also requires little effort for posting by DNR managers. On the negative side, this strategy is most restrictive on major users of these sites, since season and area closures are applied to an area larger than that of a refuge to eliminate disturbance in the vicinity of the critical protection area. These restrictions create controversy over limiting the use of one resource to protect another (e.g., fish vs. waterfowl, if fishing seasons are limited during the waterfowl breeding or migration period). There is no flexibility to alter the timing of the restrictions for annual variable phenologies, such as walleye and northern pike spawning seasons or waterfowl breeding and migration seasons.
6. **Public awareness campaigns.** This strategy is the most acceptable approach to all users, since it involves no restrictions on use. It informs and educates the public; thus this option should be an integral part of all other options. On the negative side, this alternative used alone probably does not reduce disturbance enough to encourage greater fish and wildlife use and to protect existing populations. It is difficult to assess the benefits and effectiveness of this option.

Re-establishment of Aquatic Macrophytes

(See Tables A.1, A.2 for ecological requirements of selected aquatic macrophytes.)

Strategies

1. **Revegetation with a drawdown.**
2. **Transplanting or seeding,** using one or more of these techniques:
   - Planting/burying seeds, sprigs, rhizomes, other propagules, or plugs of vegetation by machine or hand into exposed mudflats or submerged sediments.
   - Submerging to the bottom individually weighted propagules; propagules inserted in clay balls, peat cups, mesh bags, or paper towel envelopes weighted with gravel; or propagules attached to netting, wire, or rope.

Potential Benefits

1. Increased food and cover for macroinvertebrates, fish, and wildlife.
2. Increased foraging, nesting, and egg-laying substrate, cover, and nursery areas for fish, wildlife, and macroinvertebrates.
3. Improved water quality from filtration, settling of suspended solids, nutrient uptake, and production of allelopathic substances suppressing phytoplankton.
4. Reduced resuspension of bottom sediments and nutrients from attenuated waves.
5. Improved fishery for game fish and, consequently, reduced and controlled undesirable fish populations.

Evaluation of Strategies

1. **Revegetation with a drawdown.** This strategy provides the most immediate and encompassing results, with no direct cost for seeds or propagules. It allows quick natural revegetation and also allows efficient transplanting of desirable aquatic macrophytes. By compacting bottom sediments, the drawdown reduces the effects of wave action after reflooding. This strategy is very effective in combination with other techniques, especially control of undesirable fish. On the negative side, this strategy is often not feasible due to municipal and industrial needs, and it is not acceptable to recreationists, property owners, and commercial and sport fishing interests. It is also potentially harmful to key fish and wildlife species (e.g., lake sturgeon and Forster's tern). This technique has physical limitations, including bottom contour, inflow-outflow characteristics, and water level control-structure capabilities. Oxidation and decomposition of organic materials result in short-term increases in available nutrients after reflooding. Undesirable species (e.g., purple loosestrife) could colonize exposed mudflats.
2. **Transplanting and seeding.** Transplanting and seeding are applicable to a wide variety of conditions, but usually require other habitat manipulations to improve conditions for survival. These strategies are proven effective if planting effort is carefully planned and linked to other habitat improvement projects. These plantings quickly provide food and cover for waterfowl and fish. Propagules are readily available from several sources. Minimal equipment and labor may be required, but often costs for materials and especially for labor will be high, depending on the specific technique most applicable to given conditions. Furthermore, transplanting and seeding typically require other habitat management applications, such as improved water clarity, lower water levels, and wave attenuation, to mitigate effects of limiting factors. Protection from strong wave forces and undesirable fish may be required during initial growth. High water clarity is required for submerged macrophyte seedings, since seedlings have only limited nutrient reserves to produce enough growth for adequate photosynthesis. Drawdown is required for emergent macrophyte seedings. The public may view these strategies as a conflict of interest, especially if propagule transplants are harvested from areas where public harvesting is prohibited or if propagules are transplanted in areas where the public or other agencies are harvesting. Research is needed to evaluate harvesting and planting techniques, site selection criteria, and aquatic macrophyte biology and ecology.

Photo by the author.

COMPREHENSIVE MANAGEMENT STRATEGY FOR SHALLOW LAKES: A GENERALIZED EXAMPLE

Overview

Due to the numerous factors that contribute to declining fish and wildlife habitat quality and the complexity of their interactions, the most effective approach to managing large, shallow lakes is through a comprehensive management strategy involving multidisciplinary participation. A comprehensive management strategy involves two phases: development of a comprehensive management plan and implementation of the plan. The comprehensive management plan summarizes pertinent baseline data for a system, describes factors negatively impacting natural resources, delineates management goals for wildlife, fish, and water resources, and recommends specific management objectives, options, and responsibilities. Such a plan will require several or all of the strategies described below, depending on site characteristics, primary problems, and management objectives. Implementation of the plan involves acquiring funding, delegating responsibilities for implementing the recommended strategies, and directing and evaluating actual implementation.

A generalized comprehensive plan that incorporates the major components from this appendix follows. *The Winnebago Comprehensive Management Plan* (Wis. Dep. Nat. Resour. 1989*a*) and the lower Green Bay remedial action plan (Harris 1987) provide excellent examples of the application of this ecosystem approach to management of large water bodies.

Strategy

Inter-agency Task Force

- Representation from appropriate government agencies and user groups such as the DNR, Soil Conservation Services, County Land Conservation Committee, Lake Management District, University of Wisconsin-Extension, U.S. Army Corps of Engineers, local government agencies, industry, recreational boaters, lakeshore property owners, and hunting and fishing organizations.
- Appointment of technical advisory committees with expertise in key problem areas such as nutrients and eutrophication, biota and habitat, toxic substances, and users.

Public Education and Involvement

- Public meetings.
- Newspaper, radio, and television news releases.
- Presentations to interested groups and agencies.
- Newsletter.

Watershed Management Plan

Sedimentation and nutrient loading from watershed erosion are primary problems for most large lakes in southern Wisconsin. Therefore, to achieve long-term improvements of the greatest magnitude in most large, shallow lake ecosystems, watershed management is essential. But other in-lake factors (e.g., waves, undesirable fish, fluctuating water levels) that partially control abundance of aquatic macrophytes and macroinvertebrates must also be addressed.

- Inter-agency cooperation and involvement.
- Development of a Geographic Information System to manage, process, and integrate data on soil types, topography, land use, land management practices, watershed hydrology, water quality, sources of pollution, etc.
- Assessment of sources, amount, and type of nonpoint and point source pollution.
- Barnyard and animal waste control.
- Implementation of soil and water conservation practices for agricultural lands and construction/development projects.
- Promotion of proper techniques, rates, and site selectivity for pesticide and fertilizer applications.
- Sanitation district improvements and correction of faulty septic systems.
- Industrial pollution abatement/reduction.
- Wetland protection/restoration projects; utilization of other types of sediment traps.
- Urban stormwater diversion/reduction.
- Land-use planning and zoning improvements and stricter building codes.
- Ground water quality monitoring and well-testing.

Eutrophication Control (in-lake methods)

- Control/removal of undesirable fish.
- Biomanipulation.
- Nutrient inactivation, precipitation, covering, or removal.
- Aquatic macrophyte control/removal.
- Dredging.
- Dilution/flushing.

Water Level Management

- Cooperation with U.S. Army Corps of Engineers, property owner associations, resource user groups (anglers, hunters, trappers, nonconsumptive users, boaters), industry, and municipalities, to develop improved management plans designed to enhance aquatic macrophyte growth.
- Review of dam operating orders and water level management.
- Review of hydrologic and water level data.
- Stabilization and maintenance of the lowest acceptable late spring and summer levels to enhance macrophyte growth.

- Maintenance of fall levels until freeze-up to preserve furbearer habitat.
- Implementation of a winter drawdown and maintenance of winter levels until after ice-out to reduce or eliminate ice scouring and excessive flooding. (Minimum winter levels should not expose mudflats; this can cause frost damage to overwintering propagules.)

Control of Undesirable Fish

Complete eradication through a drawdown and application of fish toxicant where feasible, followed by biomanipulation of predator fish populations.

- Restocking of predators, especially adult fish.
- Creation and/or improvement of spawning habitat for predator fish.
- Re-establishment of aquatic macrophytes.
- Prevention of winter-kill problems after reflooding.
- Barriers to undesirable fish.

Partial treatment.

- Promotion, support, and subsidy (if necessary) of commercial fishing.
- DNR spot treatments of spawning and feeding concentrations.
- Biomanipulation.
- Application of species-specific attractants, sterilants, and treated baits, when developed.

Aquatic Macrophyte Management

Re-establishment.

- Species selection.
- Planting methods and planting size.
- Site suitability, including water clarity, bottom substrates, and protection requirements from wave action and undesirable fish (see Tables A.1, A.2).

Species composition management.

- Reduction/eradication of nuisance species.
- Control methods, timing, extent, and location strategies to favor desirable species.

Aquatic macrophyte harvesting.

- Determine extent and impact of nuisance plant harvesting and commercial harvesting.
- Regulation of harvesting if necessary.

Wave Attenuation

Shoreline and marsh-edge protection designed to allow access to spawning marshes.

Wave barriers.

- Artificial breakwater, island, and reef construction.
- Living breakwaters through re-establishment of emergent macrophytes (especially hard-stemmed bulrush, common reed, and wildrice).

Disturbance Reduction

- Refuging options (type, location, size).
- Restricted fishing and hunting seasons or areas.
- Public awareness/education campaign.

Information Needs (Research)

- Status and ecology of target fish and wildlife species.
- Status of aquatic macrophyte and macroinvertebrate communities.
- Status of undesirable fish populations.
- Factors limiting aquatic macrophytes and macroinvertebrates.
- Water quality and sources of turbidity.
- Presence and sources of contaminants.
- Extent and sources of nonpoint pollution.
- Water level and hydrologic data.
- Nutrient loading sources.
- Extent and sources of disturbance, as related to location of critical fish and wildlife habitats and food resources and location of high public-use areas.
- Status and attitudes of various user groups.

Evaluation

Monitor response of:

- Fish and wildlife species.
- Water quality.
- Water levels.
- Aquatic macrophytes.
- Aquatic invertebrates.

Monitor condition and performance of structures.

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Ecological Requirements of Selected Aquatic Macrophytes

(See Tables A.1, A.2, above.)

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APPENDIX B. *Scientific names of pertinent species.*

Species Mentioned in Text	Scientific Name
canvasback	*Aythya valisineria*
lesser scaup	*Aythya affinis*
ruddy duck	*Oxyura jamaicensis*
American coot	*Fulica americana*
Forster's tern	*Sterna forsteri*
common carp	*Cyprinus carpio*
freshwater drum	*Aplodinotus grunniens*
bluegill	*Lepomis macrochirus*[*]
yellow perch	*Perca flavescens*
largemouth bass	*Micropterus salmoides*
walleye	*Stizostedion vitreum vitreum*
northern pike	*Esox lucius*
bullheads	*Ictalurus* spp.
lake sturgeon	*Acipenser fulvescens*
fingernail clams	*Sphaeriidae*
American wildcelery	*Vallisneria americana*
sago pondweed	*Potamogeton pectinatus*
bladderwort	*Utricularia* sp.
coontail	*Ceratophyllum demersum*
watermilfoil	*Myriophyllum* sp.
Canadian waterweed	*Elodea canadensis*
naiad	*Najas* sp.
Eurasian watermilfoil	*Myriophyllum spicatum*
curlyleaf pondweed	*Potamogeton crispus*
pondweeds	*Potamogeton* spp.
annual wildrice	*Zizania aquatica*
hard-stemmed bulrush	*Scirpus acutus*
common reed	*Phragmites communis*
purple loosestrife	*Lythrum salicaria*

[*]Historical references to bluegill in the text likely include other species of sunfish.

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Approximate Metric-English Equivalents
1 ha = 2.47 acres
1 m = 3.28 ft
1 cm = 0.39 inches
1 km = 0.62 miles
1 m^2 = 1.20 yd^2

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