Mechanical and habitat manipulation for aquatic plant management : a review of techniques. No. 77 1974

Nichols, Stanley A.

Madison, Wisconsin: Wisconsin Department of Natural Resources, 1974

MECHANICAL AND HABITAT MANIPULATION FOR AQUATIC PLANT MANAGEMENT

A Review of Techniques

UPPER GREAT LAKES REGIONAL COMMISSION

An Inland Lake Renewal and Management Demonstration Project Report

1974

Technical Bulletin No. 77
DEPARTMENT OF NATURAL RESOURCES
Madison, Wis.
1974

A Cooperative Effort of the University of Wisconsin and the Department of Natural Resources

Sponsored by the Upper Great Lakes Regional Commission

ABSTRACT

Harvesting and habitat manipulation techniques, along with the requisite biology and planning, are reviewed with regard to managing nuisance aquatic plant growths.

Harvesting has beneficial ecological implications as it removes the problem biomass from the water and its cost and effectiveness have the same magnitude and variability in results as does chemical treatment with herbicides.

Habitat manipulation involves a somewhat broader array of management techniques and includes shading with dyes and black sheeting, dredging, sand or gravel blanketing, overwinter drawdown, and nutrient limitation. Of these techniques overwinter drawdown, dredging to a depth below the photic zone, and shading with black plastic sheeting appear to be effective treatments. Sand and gravel blanketing show initially encouraging but short-lived results. The results of dyes, and nutrient limitation, yield rather inconclusive results.

PREFACE

The Inland Lake Demonstration Project, since its inception in 1968, has been concerned with the development and demonstration of ways to manage, protect, and where necessary, restore lake resources. Substantial attention has been directed towards nonchemical means for dealing with aquatic plant problems. There has been a large demand in recent years for an overview of this suite of management alternatives and this report has been prepared to meet that need.

The report is aimed at a rather diverse readership. On one hand we are transferring new research findings or summarizing the technical state-of-the-art for professionals who are concerned with aquatic plant management problems. On the other, we are trying to inform project initiators and/or decision-makers (lake property owners and their organizations, local governmental officials, educators, and generally concerned citizens) about lake management options which were previously unknown to them. This need to reach two rather different audiences–one largely scientific and the other largely lay–has resulted in a report with a "split personality". To improve readability, Dr. Nichols has placed recent research findings and the more technical data in the appendixes, thereby limiting the technical level of the report itself. We hope the reader will not be impeded by this organizational choice and that the report will be useful to a much wider audience.

Stephen M. Born, Project Director
Inland Lakes Demonstration Project

MECHANICAL AND HABITAT MANIPULATION FOR AQUATIC PLANT MANAGEMENT

A Review of Techniques

Stanley A. Nichols

Technical Bulletin No. 77
DEPARTMENT OF NATURAL RESOURCES
Madison, Wis.
1974

CONTENTS

INTRODUCTION

Dense growths of aquatic plants can interfere with irrigation, shipping, fishing and recreation; they can also create health problems. In the upper Midwest, aquatic plant problems most significantly affect the recreation industry. Rooted aquatic plants (macrophytes) and algae become a nuisance to fishermen, boaters and bathers, reduce aesthetic values of a pond or lake, and lead to declining fisheries. Klessig and Yanggen (1972), for example, found that more than 60 percent of the Lakeshore Property Owners' Associations in Wisconsin indicated that problems with aquatic plants or algae existed in their lake. The control of aquatic plants is, therefore, a major consideration in lake management.

A person wishing to undertake a plant management program can choose one or several basic alternatives: chemical control, biological control, mechanical control, or habitat manipulative controls.

Chemical treatment involves the use of herbicides and can be very effective in controlling plants, depending on the type of plant and the type of chemical used (Little 1968b; Lueschow 1972). Large areas can be treated rapidly and in shallow water. The cost of the treatment varies from nominal to expensive, depending on the type of chemical, the effectiveness of the treatment and the size of the area treated. Because the ecological implications of using large doses of herbicide in the water system are not well understood, the practice should be approached with caution.

Biological controls include predation by herbivorous fish, mammals, waterfowl, insects and other invertebrates, diseases caused by microorganisms and competition from other aquatic plants (Little 1968b). Still largely in the experimental stage, these methods may provide ultimate long-term control, but as yet they do not have general field applicability to the situations found in the upper Midwest. They must also be used with discrimination to avoid substituting one problem for another.

The purpose of this report is to discuss the last two plant management methods: *mechanical control* by means of harvesting and *habitat manipulation,* which includes such techniques as: overwinter drawdown, dredging, sand blanketing, the use of dyes, and nutrient limitation and inactivation. To preface a review of both methods, the pertinent biology of aquatic plants and the types of information useful in an effective management program will be discussed. Results from the demonstration efforts from several Inland Lake Renewal Projects will be integrated into the review with the more technical aspects being referenced or discussed in greater detail in an appendix.

BIOLOGY AND HABITAT OF AQUATIC PLANTS

In order to design, assess and utilize management techniques, a basic understanding of the biology of aquatic plants and the habitat in which they grow is necessary. This discussion should include such things as: the weedy nature of some aquatic plants, the types of aquatic plants, the critical environmental factors which influence the growth and distribution of plants, and the anatomical and morphological factors relevant to a harvesting program.

The Aquatic Plant as a Weed

In general, aquatic plants are a desirable and necessary part of the aquatic ecosystem. The excessive growth of many species in given locations can have undesirable aesthetic or economic consequences for man and can become a problem. In summarizing this problem, Sculthorpe (1967) states, "One of the major consequences of the luxuriant vegetative growth and adventive spread of hydrophytes is that numerous species attain prime importance as insidious weeds. Indeed, since about 1850 almost the only interest in these hydrophytes has been the desire to extirpate them."

The term "weed" has no precise biological definition. A weed is usually considered to be a plant without utility or beauty, growing wild and rank, and cumbering the ground or hindering superior vegetation (Harlan and de Wet 1965). Curtis (1959) points out that weeds have many biological properties in common. They generally have a rapid growth rate, can surmount high interspecific competition, show great tolerance to regressive influence, can spread and invade in large numbers and have seeds that are tolerant of extreme fluctuations in conditions.

As an example, Eurasian water milfoil (*Myriophyllum spicatum*) embodies the weedy nature of many aquatic plants. In Currituck Sound, North Carolina, reports of the species were first received in 1965. At that time, approximately 100 acres were in the infestation stage and 500–1,000

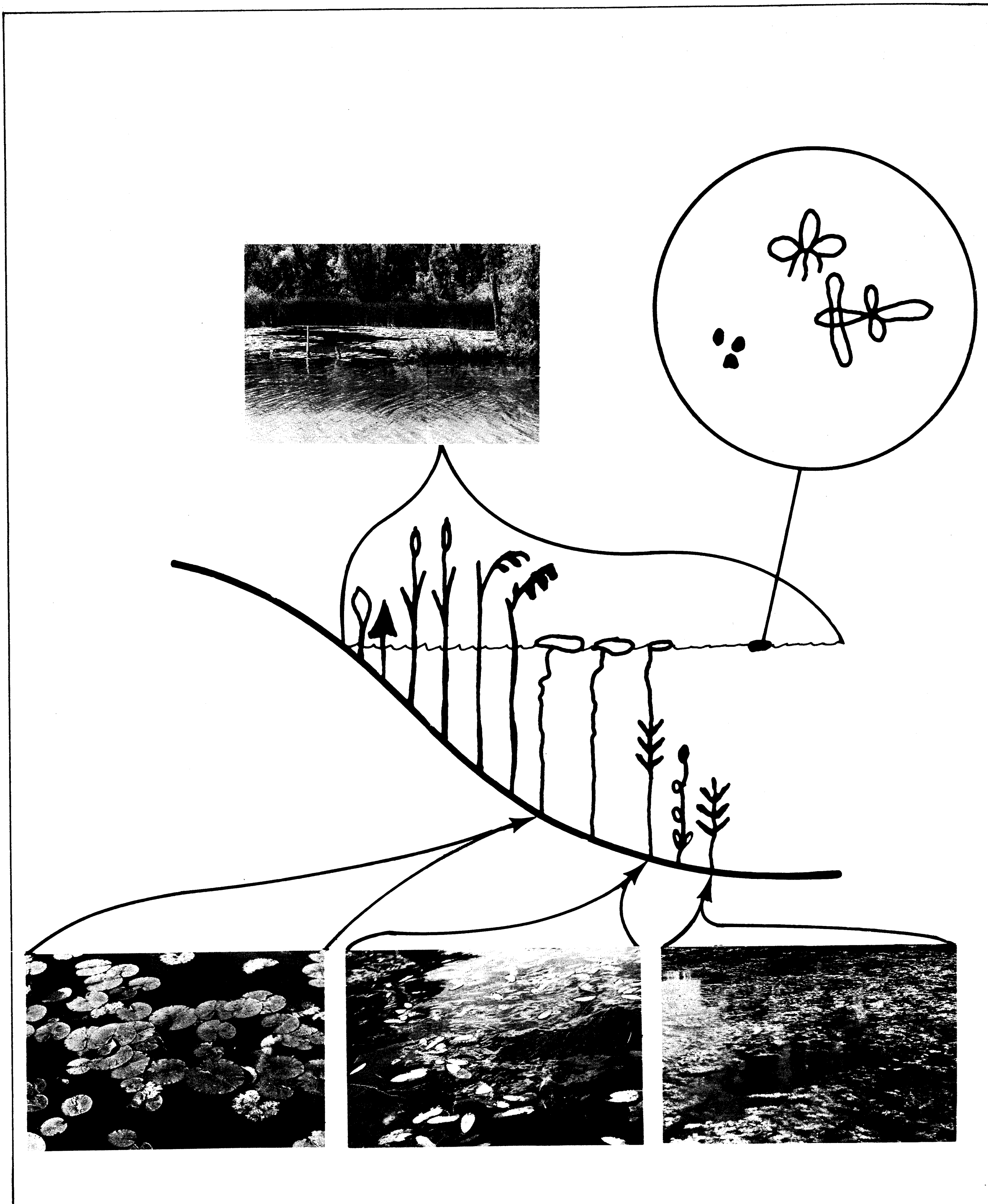


FIGURE 1. *Types of distribution of macrophyte plants.*

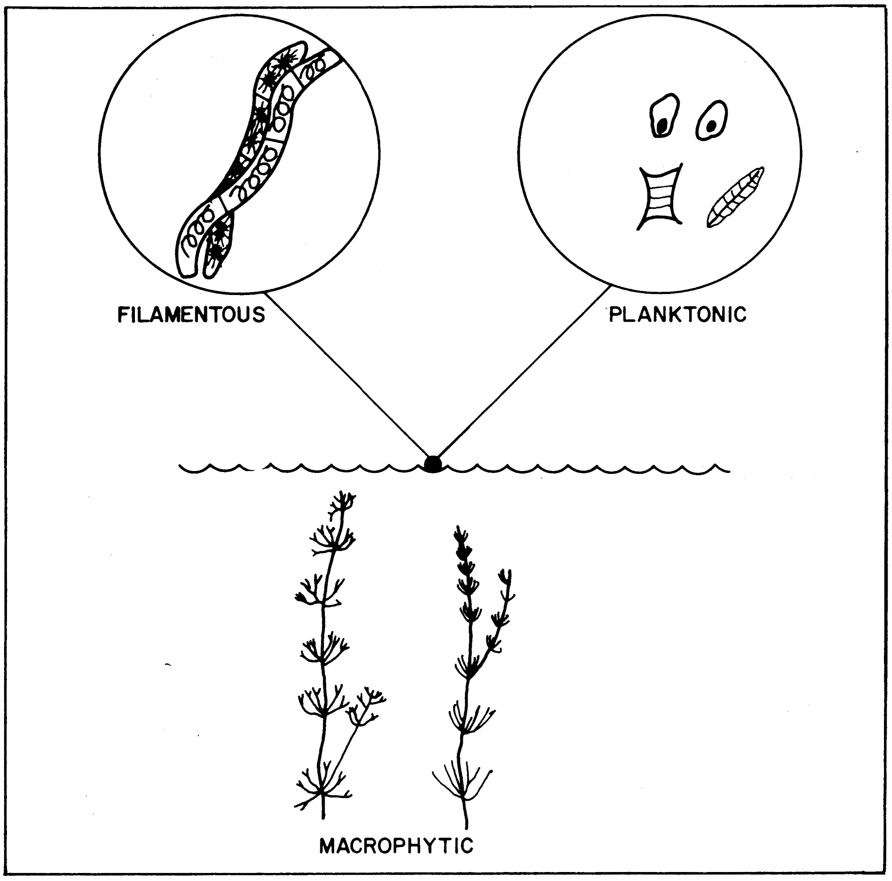


FIGURE 2. *Characteristic types of algae.*

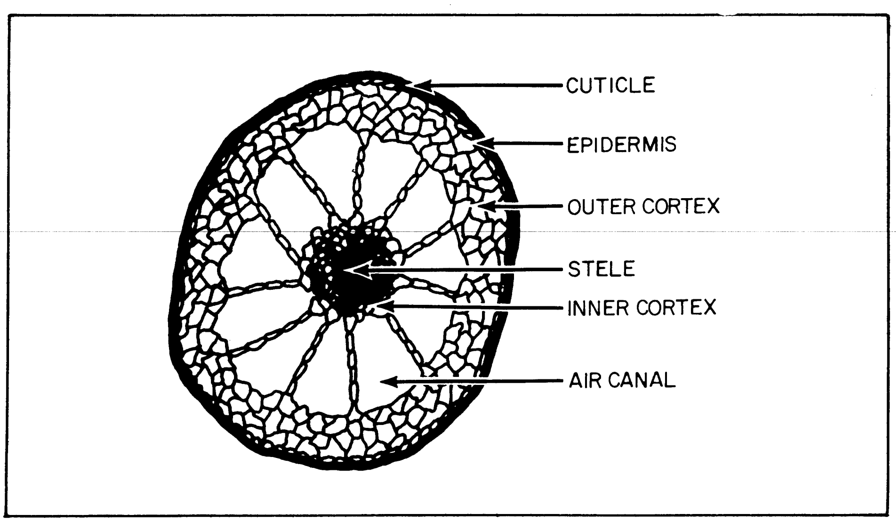


FIGURE 3. *Cross section through a stem of Myriophyllum spicatum. (From Koegel et al. 1972)*

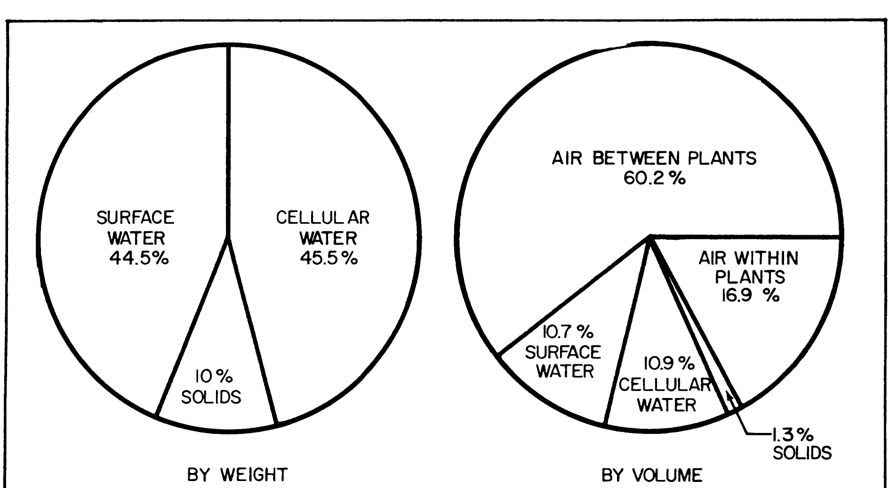


FIGURE 4. *Percentages of the constituents of as-harvested milfoil (from Koegel et al. 1972).*

constituents of the plants, primarily nitrogen, phosphorus and organic matter. Gerloff and Krombholz (1966) reported nitrogen values ranging from 1.48 percent to 4.43 percent and phosphorus values ranging from 0.10 percent to 0.75 percent dry weight as being common for six macrophyte species in a fertile Wisconsin lake and four species in an infertile Wisconsin lake. The higher values were found in the fertile lake.

Nichols (1971) found a milfoil biomass (ash-free dry weight) of 10,222 lbs/acre (1,146 g/m^2) in areas of highest growth in Lake Wingra, Wisconsin. Although some aquatic communities such as cattail marshes may have a higher biomass, Nichols' estimate is certainly one of the higher values likely to be found in a submergent community. By harvesting, both biomass and nutrients are removed from the lake. The magnitude of this removal will be discussed in a later section.

Habitat Requirements

Organisms and their environment are inseparably interrelated, acting and reacting upon each other. The environmental factors that influence a plant can be divided into two general groups, the biotic or living group and the abiotic, or nonliving group. Together they define the habitat in which a plant can live. The biotic group contains the predators, parasites, and other organisms which depend upon or compete with an organism for their livelihood. These interrelationships form the basis for biological plant management methods. The abiotic factors form the basis for plant control techniques involving habitat manipulation, and include those physical and chemical attributes which are necessary for plant growth and development: light, bottom type, water, temperature, wind, dissolved gases and nutrients. Light, water, temperature, dissolved gases and nutrients relate to the plant's ability to carry out the vital processes of photosynthesis and respiration. Bottom type and wind relate to specific physical locations where a plant can grow. The following discussion will show the relationship between critical habitat requirements and possibilities for management.

Both the quantity and quality of light influence plant growth. Light in the red and blue spectral bands is used for photosynthesis; low and high light intensities inhibit photosynthesis. Management activities that make use of shades and dyes, for example, are based on limiting light intensity or changing the spectral qualities of the light. Deepening the lake through dredging or damming is another method of altering the light available to a plant, as light is naturally attenuated in water and the spectral qualities changed.

In the aquatic environment, water is available in abundance and is therefore often overlooked as being critical for aquatic plants. Yet, aquatic plants are adapted to growing in an environment with an abundant water supply and are, therefore, sensitive to water stress. Macrophytes might be controlled by removing their water supply, resulting in the desiccation of the plant.

Plants are generally tolerant of a wide range of temperatures, and temperature fluctuations in the aquatic environment are smaller than in the surrounding aerial environment. Therefore, plant management schemes involving temperature effects depend on artificially exposing aquatic plants to the harsher aerial environment, where not only temperature but desiccation and other factors aid in controlling plant growth.

The two gases oı prımary importance in the aquatic system are carbon dioxide and oxygen, which are used for photosynthesis and respiration, respectively. The availability of carbon in the form of free CO_2 or bicarbonate appears to influence the distribution of some plant species (Hutchinson 1970). Although oxygen is many times limiting in the aquatic system, most plants are adapted to living in low oxygen conditions. Because the carbon dioxide reaction is so well buffered by an equilibrium with CO_2 in the air and because the plants are tolerant to low oxygen supplies, the success of any scheme to manage plants by altering the dissolved gases in water seems doubtful.

Many weed problems are blamed on nutrient enrichment (eutrophication) of the water. Nitrogen and phosphorus are the two nutrients of prime concern (Vollenweider 1968, Sawyer 1947, Stewart and Rohlich 1967). The aquatic system is difficult to analyze chemically in relation to the plant, because the physiology of aquatic plants is not well enough advanced for researchers to always relate nutrient data to plant productivity. For instance, Schults and Maleug (1973) have demonstrated, at least for phosphorus, that rooted aquatics will remove nutrients from both the sediment and water media. Gerloff and Krombholz (1966) and Gerloff (1969) point out that the concentration of nutrients in the habitat may not be related to the concentration in the plant, depending on the availability of the nutrient. Plants not only remove the amount of nutrients they require, but if available, they will remove nutrients in excess of their needs (i.e., luxury consumption, Gerloff 1969). Chapman et al. (1968) have also described the ability of aquatic plants to concentrate elements from their environment. These excess nutrient supplies could be used at times when the plant undergoes nutrient stress. These factors inherent in the biology of the plant will have to be overcome when developing practical, in-lake methods of nutrient limitation for macrophyte control.

All the above factors are interrelated and follow Liebig's Law of the Minimum, which states that any condition that approaches or exceeds the tolerance limits of the plant becomes a limiting condition. By manipulating the plant's environment, management tries to induce these limiting conditions and thus restrict the growth of the plants.

Wind and bottom type are physical conditions that may limit plant growth. Heavy winds tear and uproot the plant, and soil types that are too coarse or are not consolidated enough make rooting very difficult. Some bottom types are rich in nutrients essential for plant growth. Substrates might be altered by removing or covering. Wind action, however, is very difficult to control.

The Use of Biological Information in an Effective Management Program

With proper background information, management techniques in general and specifically harvesting and habitat manipulation can be used much more effectively and efficiently. Biological parameters such as an identification of plant species, their growth patterns and distribution should be superimposed on the recreational, aesthetic and commercial needs of lake users and the environmental values of the lake in designing and implementing a management strategy.

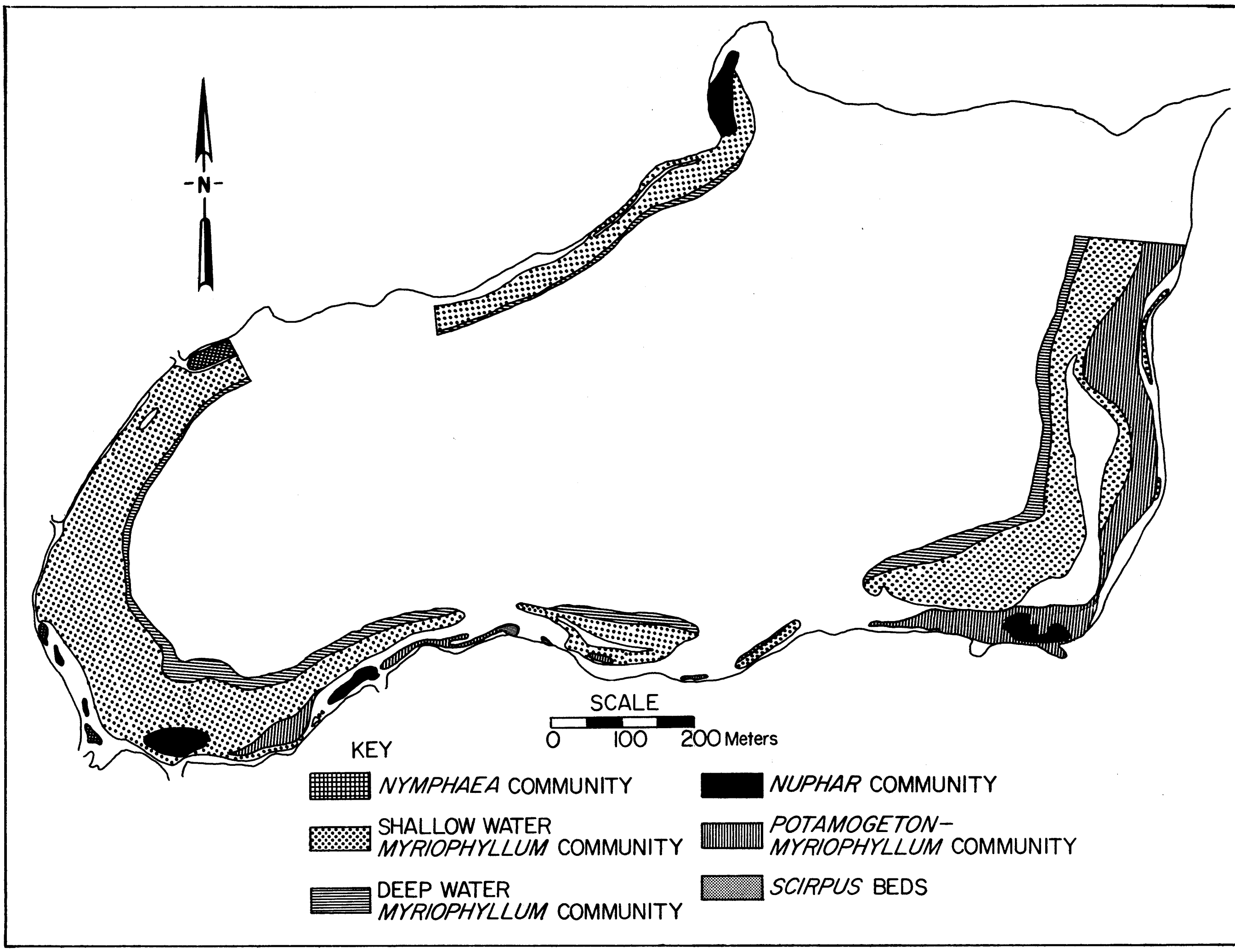


FIGURE 5. *Map of Lake Wingra showing the location of plant communities (from Nichols and Mori 1971).*

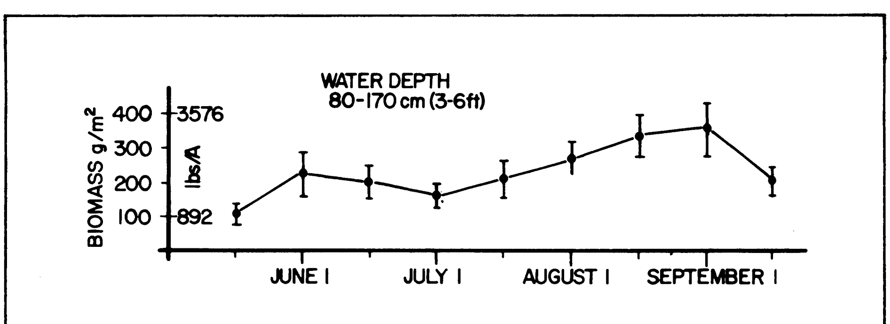


FIGURE 6. *Growth curve for milfoil in Lake Wingra (from Nichols 1971).*

Species considerations are important both to define the problem and to ascertain which management technique or techniques will be feasible and effective. Some species are a very valuable part of the ecosystem and should be preserved. Others should be eradicated quickly. Each species has individual differences, and varies greatly in its response to different management techniques.

Growth patterns will vary between species and a knowledge of the growth pattern of a plant is valuable in planning the timing of treatment. For instance, the timing for harvests will be optimum when it will result in the removal of the maximum amount of biomass and still allow full recreational use of the lake.

The distribution of plants in a lake can be mapped through aerial photography or ground reconnaissance. One can then determine where the weed problems occur in relation to the high priority areas such as boat launching sites, navigational routes and swimming beaches.

A study using these criteria was done by Nichols (1971) in an effort to prescribe a harvesting program for Lake Wingra, Wisconsin. First, the plant communities in the lake were mapped and the species identified (Fig. 5) (Nichols and Mori, 1971). The area causing the most acute problem was the community composed primarily of Eurasian milfoil in water depths from 3 to 6 ft (80-180 cm). Milfoil characteristically has two growth peaks during the summer (Fig. 6); previous studies had shown that two harvests would significantly reduce the biomass of milfoil (Cottam and Nichols, 1970). Therefore, two harvests were recommended just before the two biomass peaks. It was also discovered that the peak biomass of milfoil occurred at a later date as water depth increased. A nomogram relating the water depth to peak biomass was developed and used to schedule harvests. A second nomogram was developed showing the amount of biomass which can occur at a given depth; thus harvesting operations could be restricted to the areas with problem biomasses, instead of the total depth range of the plant.

To maximize the beneficial use of the harvesting machine the following recommendations were made: A zone from the shore to a depth of 2 ft (60 cm) should not be harvested. Only lightly stocked with milfoil, this zone was well stocked with beneficial pondweeds. A zone between 2 ft (60 cm) and 6 ft (180 cm) should be harvested beginning about June 1 and progressing from shallow to deep water. The areas next to the pondweed beds should be harvested only once before June 15 to allow pondweeds to spread into an open area during their peak growth in mid-June and to eliminate the necessity of further harvests that would set them back. The remainder of the area could be harvested a second time starting the first week of August. In areas where the plant does not restrict human activities and in deep water areas, a single harvest for thinning purposes, made most effectively during midsummer, should be sufficient.

Clearly, such intensive studies cannot be made on every lake that has a weed problem. The Lake Wingra study can, however, serve as a model of the sorts of studies that should be done on various lake types with different aquatic plant problems requiring different treatment methods. Treatment results can then be analyzed and the technology can be transferred to similar lakes with similar problems.

MANAGEMENT USING MECHANICAL HARVESTING EQUIPMENT

This section will discuss the effects of harvesting on the aquatic plants involved and water quality improvement, then describe the types of machinery available, satisfaction or dissatisfaction of persons involved with harvesting operations, costs and the uses or potential uses of the harvested plant materials.

Biological Effects of Aquatic Plant Harvesting

In determining the effectiveness of a weed harvesting program, a number of questions must be answered: What are the short-term effects of harvesting? What are the long-term effects? Is there a change in the aquatic plant community? Does harvesting cause other problems once the weeds are removed?

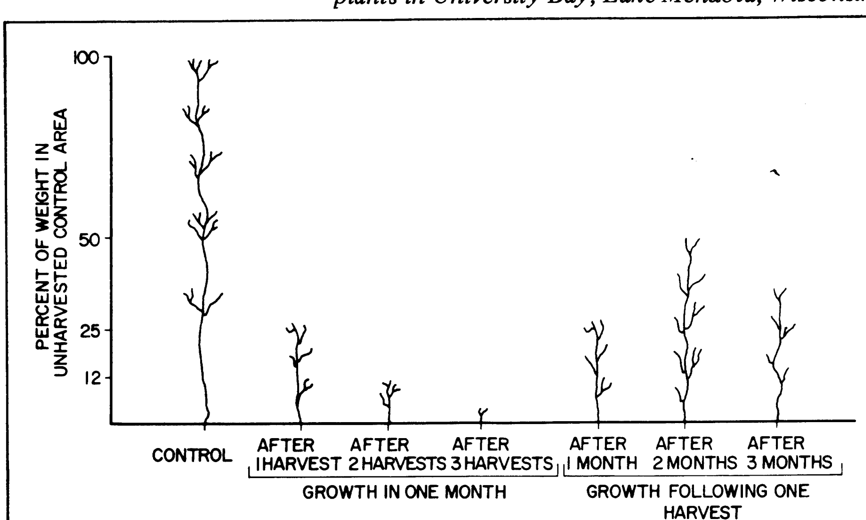
Comprehensive studies addressing these questions were made by Mossier (1968), Cottam and Nichols (1970) and Nichols and Cottam (1972). The target species in these investigations was the Eurasian water milfoil. In all three studies the test plots were small (0.02 acre [100 m^2]) and the plants were harvested by hand with the aid of scuba equipment and sickles. The results should therefore be viewed as the most thorough control obtainable by harvesting.

Three trends were studied: (1) the regrowth of plants after monthly cutting during the summer, (2) the regrowth of plants after a single cutting in early summer, and (3) the regrowth of plants one year after previous harvesting treatments.

Considering the regrowth of plants after monthly cuttings, the biomass of plant material, one month after one harvest, was reduced to a level approximately one-fourth that of the original amount. One month after a second harvest, the plant material was reduced by another one-half to about 12 percent of the control. Three harvests virtually eliminated all plant material for that year (Fig. 7).

The regrowth of plant material after a single cutting was about two times as great two months after a single harvest as it was one month after a single harvest. However, this amount was still less than half that present in control

FIGURE 7. *The impact of harvesting aquatic plants in University Bay, Lake Mendota, Wisconsin.*



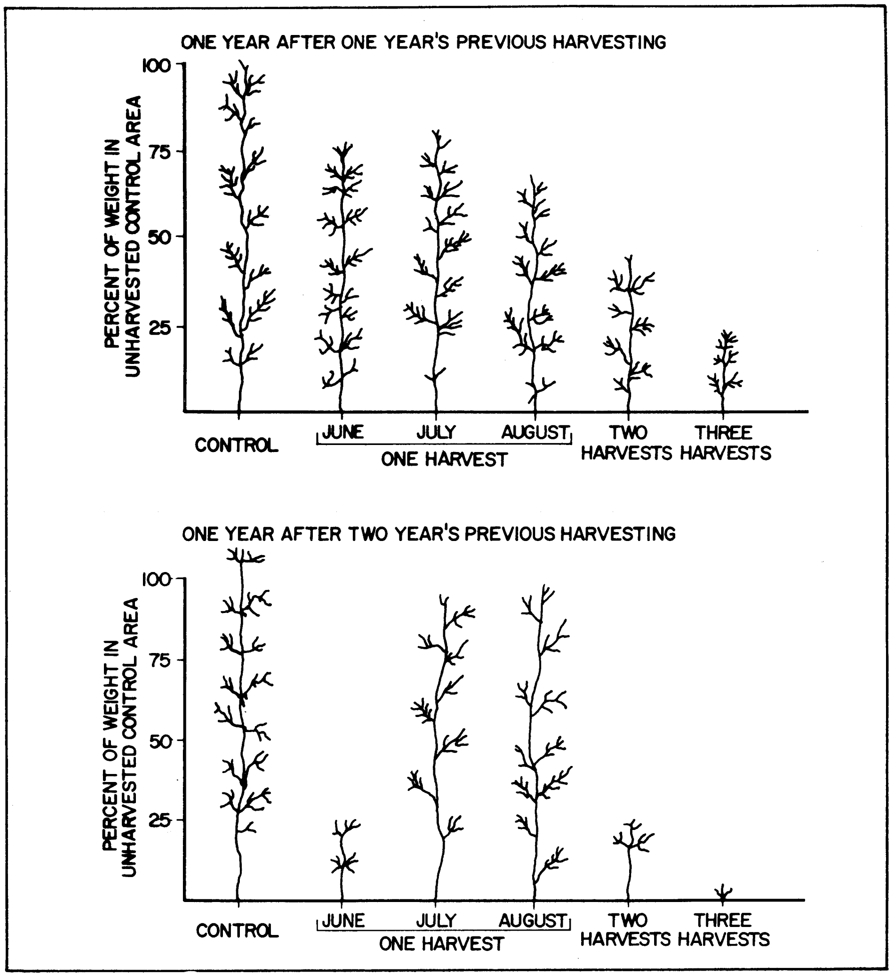


FIGURE 8. *The impact of harvesting aquatic plants in deep water stand (5 ft [150 cm] depth).*

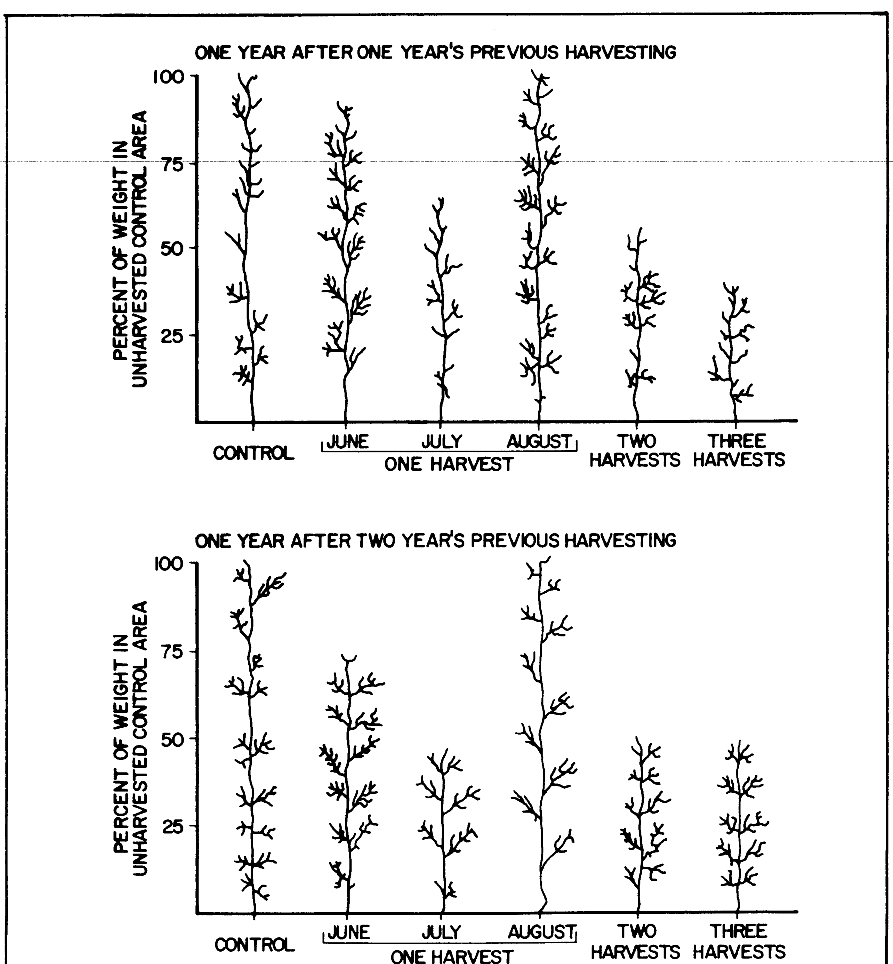


FIGURE 9. *The impact of harvesting aquatic plants in shallow stand (3 ft [90 cm] depth).*

areas. Plants dying in the fall accounted for the lower volume of plant material three months after one harvest (Fig. 7).

Harvesting one year reduced the biomass the following year, especially in deep water (depth 5 ft [150 cm]). Repeated harvesting the previous year resulted in greater control of plant growth (Figs. 8 and 9).

The reasons as to why harvesting in deep water was more effective than in shallow or why a single harvest early in the season was more effective than later in the season is not clear and an explanation is clearly speculative. It may relate to the energy balance of the plant. Early in the season milfoil is expending considerable energy in growth and reproduction. Harvesting at this time may deplete its energy reserves and hinder growth. Likewise, in deeper water, there is less energy available so more reserves are necessary for the plant to grow upward where more solar energy is available.

With the control of rooted plants one might expect, depending on the type of lake, an accompanying increase in algae, since various authors have documented an antagonistic relationship between aquatic macrophytes and algae (Hasler and Jones 1949; Goulder 1969; Fitzgerald 1968, 1969a, and 1969b). Thus a macrophyte problem could turn into an algae problem. Nichols (1973) found this to be the case in shallow areas (depth 3 ft [90 cm]) in University Bay of Lake Mendota, Wisconsin. A significant increase in the biomass of filamentous algae was found the following year after two years of harvesting. This increase accompanied a decrease in macrophytes. Whether similar algal problems would occur in other lakes certainly cannot be ascertained from this single study. One should, however, be mindful that this type of problem might occur.

Harvesting in Relation to Water Quality

The removal of plant biomass from the lake prevents the utilization of oxygen during decay and the recycling of the nutrients associated with the plants.

Jewell (1971) calculated a one-to-one ratio for the amount of oxygen needed to decompose the equivalent amount of organic matter in aquatics. Therefore, it would take 10,222 lbs/acre (1,146 g/m^2) of oxygen to decompose the equivalent amount of organic milfoil biomass found by Nichols (1971) in areas of highest growth in Lake Wingra, Wisconsin. Jewell also stated that the decay of aquatic macrophytes might be potentially more deleterious than that of phytoplankton, because macrophytes decay more than twice as fast as phytoplankton, and they decay more completely. Equal weight of macrophytes, therefore, use more oxygen and have the potential of regenerating more nutrients. Jewell equates the amount of oxygen stress put on the system by one hectare (2.47 acres) of decaying vegetation with an organic biomass of 500 g/m^2 (4,460 lbs/acre) to the dissolved oxygen demand caused by the continual discharge of untreated domestic sewage from 24,000 people over the period it takes for the decay process to stabilize (generally 2-3 weeks).

The magnitude of the nutrient removal can be quite spectacular. McNabb and Tierney (1972) reported that coontail (*Ceratophyllum demersum*) will produce 6,244 lbs/acre (700 g/m^2) in 60 days under pleioeutrophic (highly nutrient rich) conditions. If this crop were intensively managed by harvesting three times during the growing season, about 981 lbs/acre (1100 kg/ha) of nitrogen and 178 lbs/acre (200 kg/ha) phosphorus could be removed from the system. Under naturally eutrophic conditions these values would range downward from 300 lbs/acre (336 kg/ha) and 50 lbs/acre (56 kg/ha), respectively.

Lee (1970) has expressed serious doubts about the ability of harvesting to make significant inroads on the nutrient balance of a lake. Research by Neel et al. (1973) and Peterson et al. (in press) on Lake Sallie, Minnesota has confirmed Lee's prediction. They were only able to remove 221 lb (100 kg) of phosphorus and 1,590 lb (723 kg) nitrogen from the lake using extensive harvesting. These amounts were insignificant compared to the total nutrient budget of the lake. In some situations, however, where nutrient input is low, or where there is a high biomass of macrophytes in relation to the total volume of water (for instance, in shallow ponds), harvesting may remove a large enough portion of nutrients to significantly improve water quality. The question of significant removal is complicated because it will vary with each lake depending on its nutrient budget and no one is sure to what concentrations nutrients have to be reduced to become limiting to plant growth.

Types of Machinery

A variety of methods have been used to mechanically remove aquatic plants from the water. These range from hand methods and uprooting devices to large and complex machinery. The machinery and methods as well as some resultant successes and failures have been reviewed by Livermore and Wunderlich (1969).

Mechanical control measures have usually consisted of cutting the nuisance plant. The most common system for cutting aquatic plants has been a version of the reciprocating mower bar similar to the type used on agricultural machinery (Fig. 10). Hydraulic uprooting devices are manufactured, and oil skimmers have been proposed for harvesting duckweed and algae (Carranza and Walsh, 1972). The cutting bar can be small or large; it may be mounted on a boat or be part of a large harvesting system. The cut plants can be left in the lake, raked to shore in a secondary operation, or loaded onto barges by a conveyor system. Within this basic design there is a substantial size and cost differential. Larger harvesting units have a variety of accessory equipment including transport barges and shoreline unloading apparatus. Thus, prices vary, from around $500 to over $50,000 depending on the sophistication of the unit.

Table 1 lists the manufacturers of cutting and harvesting equipment common to the Midwest. Some of these manufacturers are no longer in business, but their mahcines are still in use. Since the building of harvesting equipment is more or less a "special order" business, earlier companies like Aquatic Controls made many machines, no two of which were exactly alike. All specifications given are those of the company and there is no standardization of specifications within the industry. The machinery was not field tested as part of this study.

Because of the present low demand for weed harvesting machines, the manufacturers are generally small firms and the machines more or less handmade. The production of aquatic weed harvesting equipment has not, therefore, reached the economy of size, and in many cases, of price that has been attained in the production line methods used for agricultural machinery.

TABLE 1. Manufacturers of Weed Harvesting Equipment

Company	Address	Model	Cutting Bar Capacity	Cutting Speed	Removal Method
Air–Lec Industries	3300 Commercial Ave. Madison, Wis.	–	W = 3½ ft. (105 cm) D = 3½ ft. (105 cm) Boat mounted	3–6 mph (4.8–9.6 kph)	8 ft./(240 cm) rake available for raking to shore
American Water-weed Harvesting Company	14901 Minnetonka Industrial Rd. Minnetonka, Minn.	Harvester	W = 16 ft. (480 cm) D = 6 ft. (180 cm)	3 mph (4.8 kph) 10 mph (16 kph) Transport speed	Cutter unit loads on to attached 50 ft./(15m) self-unloading barge
		Shore Line Cleaner	W = 7 ft. (210 cm) D = 4 ft. (120 cm)	3–6 mph (4.8–9.6 kph)	10 ft./(300 cm) rake available for raking to shore
Aqualogy Products Corporation	P. O. Box 505 Downers Grove, Ill.	Aqua-Beach-Comber	W = 7 ft. (210 cm)** D = 6 ft. (180 cm)	Less than 1 mph (1.6 kph)	Rake available for raking to shore
Aquatic-Controls*	Milwaukee, Wis.	Marine Scavenger	W = 10 ft. (300 cm) D = 8 ft. (240 cm)		Cutter unit loads on to attached self-unloading barge
This company also made a number of smaller units including the Dugong and Manette 45 models					
Aqua–marine	1116 Adams Street Waukesha, Wis.	650	W = 8 ft. (240 cm) D = 5 ft. (150 cm)	1½ mph (2.4 kph)	Aqua-trio combination includes self-unloading harvester, transport barge and shore conveyor
		Sawfish	W = 8 ft. (240 cm) D = 5 ft. (150 cm)	1½–2 mph (2.4–3.2 kph)	L-shaped front end loading rake
Grinwald–Thomas*	Highway 16 Hartland, Wis.	501	W = 10 ft. (300 cm) D = 5 ft. (150 cm)	2 mph (3.2 kph)	Combination of equipment with self-unloading harvester, transport barge, and shore conveyor
Hockney Company	913 Cogswell Dr. Silver Lake, Wis.	HC–10	W = 10 ft. (300 cm) D = 5 ft. (150 cm)	4 mph (6.4 kph)	Rake attachment for raking to shore
		HC–7 Boat mounted	W = 7 ft. (210 cm) D = 4 ft. (120 cm)	4 mph (6.4 kph)	Rake attachment for raking to shore
Taussig Assoc.	1625 Eye Street N. W. Washington, D. C.	Water Witch	W = 8 ft. (240 cm)** D = 10 ft. (300 cm)	10 mph (16 kph)	None at present

W = width of cut
D = maximum depth of cut
*Companies no longer produce harvesters
**This machine uses a hydraulic uprooting system, not a cutting bar.
(Current prices can best be obtained by writing directly to the manufacturers.)

With the wide range of equipment available, users must be careful to choose a machine that will best suit their particular needs. Large machines can harvest large quantities of plants in open, deep (over 3 ft. [90 cm]) water, while small, boat-mounted machines are mobile, for cutting around obstacles and in shallow water. These smaller machines, however, require a secondary operation for the removing of cut plants. In addition to the commercial harvesters, a wide variety of machines, which vary in effectiveness, have been put together by individual mechanics.

The Departments of Mechanical and Agricultural Engineering at the University of Wisconsin-Madison are working on experimental harvesting systems that will involve a high speed cutting unit and a separate pick-up and transport unit (Koegel et al. 1972; Bruhn and Livermore 1970). The transport unit will be associated with chopping and pressing facilities, thus greatly reducing the bulk and weight of aquatic plants per area harvested.

Survey of Harvesting Experiences

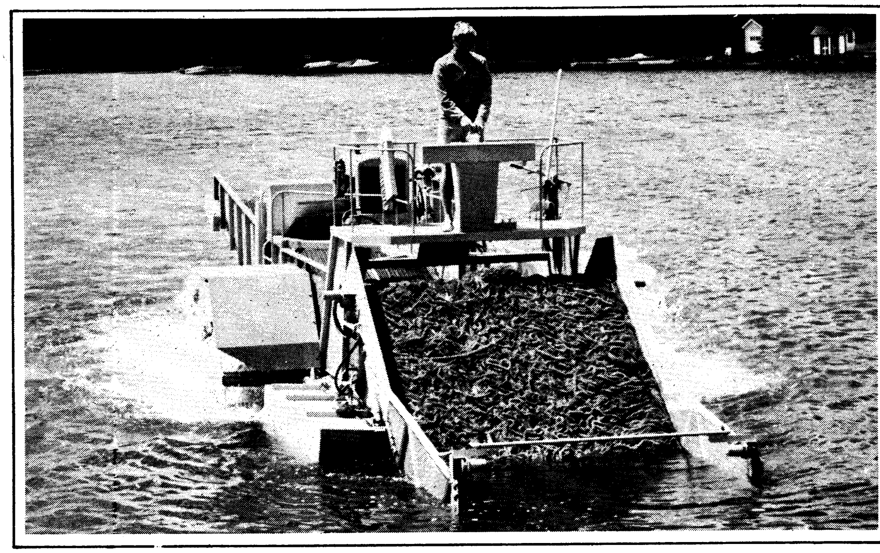
For this study the operators of harvesting equipment were also canvassed for their opinions on the use and benefits of the machinery and the attendant costs. A questionnaire was distributed to County Extension Agents, the Department of Natural Resources field personnel, Lakeshore Property Owners' Associations, governmental units and other users of harvesters in Wisconsin (Append. A). The questionnaire was also mailed to selected persons in Michigan and Minnesota.

The results of the survey are tabulated in Appendix B. Thirty-two locations where harvesting equipment had been used were identified. Three other Wisconsin locations (Shawano Lake, Shawano; Danbury Flowage, Burnett

Co.; and Pigeon Pond, Clintonville) were identified as places where people could recall past harvesting experiences but could give no further information. In addition, the Minnesota Department of Natural Resources provided a list of lakes where harvesting permits were issued (Append. C). Although some areas have undoubtedly been missed in the survey, the identified operations provide a representative overview of the experiences encountered.

The high initial investment required is probably the most serious obstacle to implementing a management program. Although the machinery can be used over a number of seasons, the initial outlay is substantial. This may prohibit a harvesting program where limited funds or political controversy are involved.

The costs of operations tallied by the survey were borne by 2 individuals, 2 private businesses, 2 civic or sportsman clubs, 10 lakeshore property owners' associations, 4 sanitary districts and 12 branches of government at the local, county, state or federal levels. Where individuals were involved, they tended to use smaller machines or had custom work done, paying the operator either by the hour or by the frontage cut. Many of the lake improvement associations and governmental units used larger machines. Klessig and Yanggen (1972) reviewed the lakeshore property owners' associations both by type and by their ability to deal with lake-related problems, a valuable reference if people want to organize for large-scale harvesting activities.



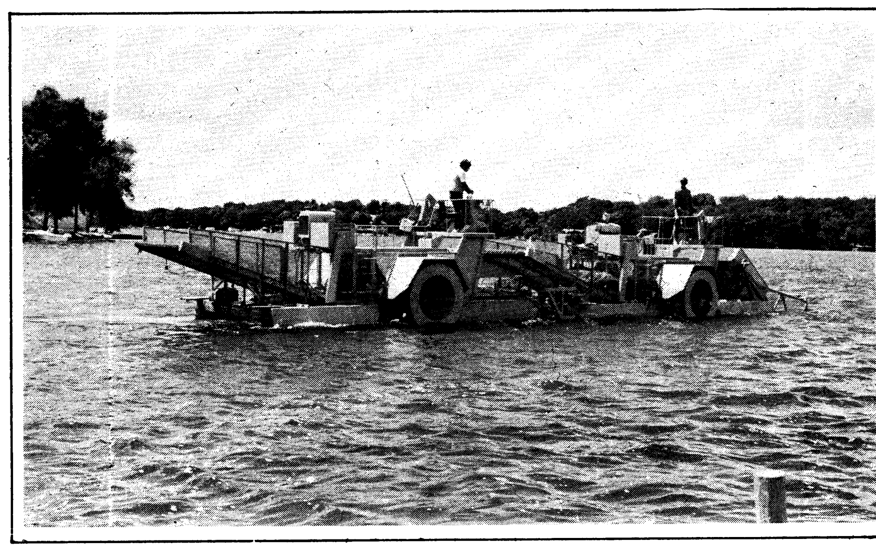
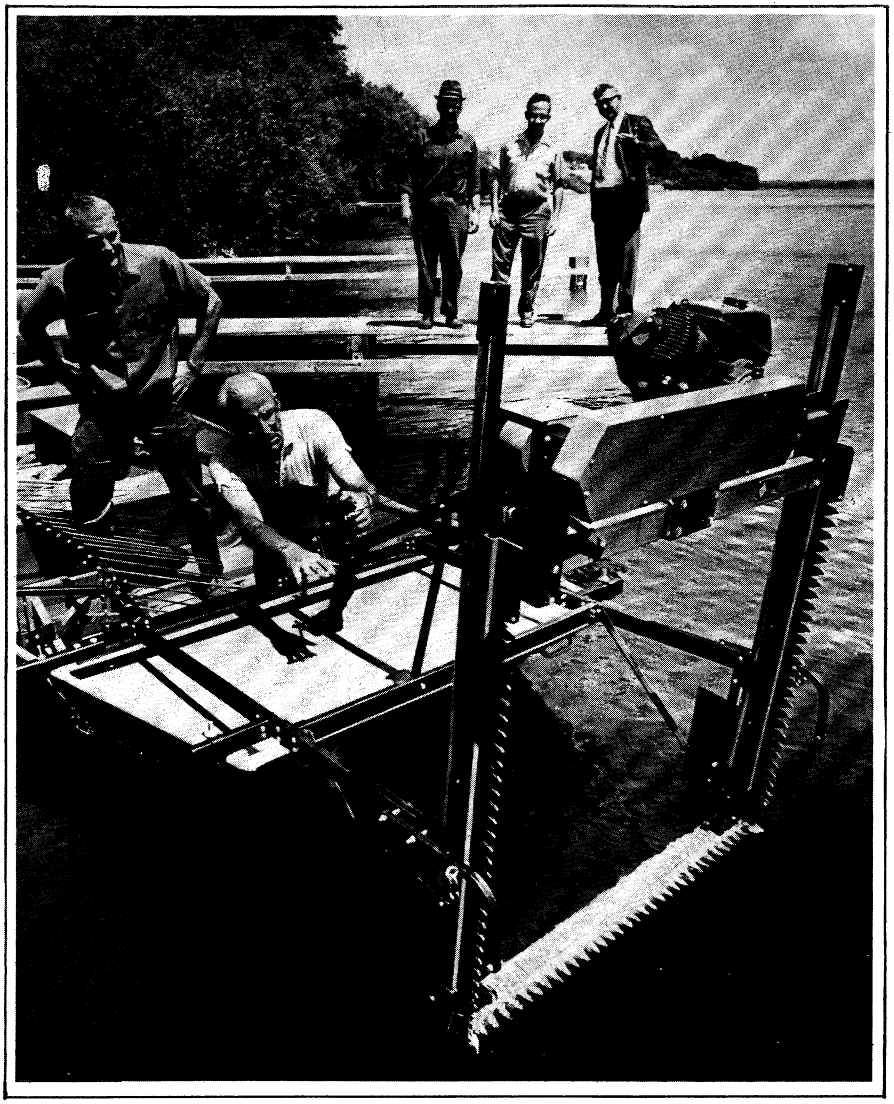


FIGURE 10. *Harvesting equipment: (a) self-contained harvesting unit; (b) harvesting unit with attached conveyor barge; (c) boat mounted weed*

The sanitary district is a special use unit of government which has been concerned primarily with waste disposal. It has the ability to issue bonds and tax people within the district; sometimes it has taken weed harvesting under its jurisdiction. Other governmental units, such as cities or counties, have used public works or park funds to finance harvesting operations. Oakland County, Michigan approached the financial problem in a rather unique fashion, making the initial investment in the harvesting equipment for its citizens and then leasing the machine to smaller units, none of which could individually support a machine. For the county the machine is self-liquidating; it is made available to those people who need it and are willing to pay for it.

The cost of harvesting operations varied considerably and the figures invite numerous interpretations. In general, it appears that close records were not kept of the costs or acreage harvested. Where a breakdown of the costs was available, they were included. Dane County, Wisconsin runs the largest operation and its costs averaged \$23 per acre (1971 costs—present costs are about \$28 per acre). In harvesting 3,500 acres of plants, the costs included operation expenses of \$35,000 and amortization of the machinery at the rate of \$45,000 a year (H. Hartwig, pers. comm., 1972). Operation expenses ran \$26 an acre at Nagawicki Lake, and \$13 an acre at Browns Lake. These figures agree with those supplied by the U.S. Forest Service (C. E. Kennedy, pers. comm., 1972), where a close accounting was kept on a weed control project in Arizona. The Forest Service estimated their operational costs, using a Sawfish cutter, at \$13.41 per acre for the working time of the machine; \$25.48 was the actual cost and included down time and repairs. These figures do not include the cost of the machine. Livermore and Wunderlich (1969) placed cost estimates at \$30 an acre for Chesapeake Bay tributaries, \$36 an acre at Winter Park, Florida, and \$50-70 an acre for Jamestown, New York.

Aquamarine Corporation (C. B. Bryant, pers. comm., 1973) has studied the performance of their machinery at four locations: Lake Wabamun, Edmonton, Alberta; Berkeley, California; Beulah Lake, East Troy, Wisconsin; and Big Bear Lake, California. They found that it cost \$6/ton (wet weight) or \$8.20/acre in Alberta, \$8.26/ton or \$23.61/acre



cutter. (Compliments of Aquamarine Corp. (a), (b), and Air-Lec Industries, Inc. (c)

at Berkeley, $4.51/ton or $12.35/acre at Lake Beulah, and $0.60/ton or $21.70/acre at Big Bear Lake in labor costs for a harvesting program. Further analysis of the data from Beulah Lake indicated that their total costs (operating and supervisory salaries and operating expenses such as gas, oil, insurance and repairs) totaled $20.17/acre or $7.38/ton. Again, these figures exclude the cost of machinery. Based on these experiences, Aquamarine has calculated a budget sheet (Table 2) for a typical harvesting operation.

In any case the magnitude and variability in the cost of harvesting are similar to those found for using chemicals (Karl 1972). It is apparent that harvesting costs in the upper Midwest are considerably less than the $450-$900 per mile of 10-foot-wide canal reported by *Weeds Today* (1972) for Florida canals. It is interesting to note that custom harvesters or leasing operations charged only $6-$15 an hour for their services.

A wide variety of plant species, primarily submergent and floating-leaved types, were harvested. There appears to be little experience in the upper Midwest with the harvesting of emergent or free floating species. Harvesting machines cannot cut emergent plants unless they are in relatively deep water (1-2 ft minimum [30-60 cm]). Björk (1972) reported the development of amphibious harvesting machines and excavators used to clear reed and sedge beds in Hornborgasjön, Sweden and as previously reported Carranza and Walsh (1972) have proposed that oil skimmers be used for harvesting duckweed and algae.

The survey showed that the weed problems were varied. Most questionnaires agreed that harvesting was beneficial for the short term; if it was done often enough and continued year after year the lake was more usable. Six persons reported long-term benefits of weed harvesting, i.e., harvesting operations could be scaled down or halted after one or more years of intensive harvesting because the weeds had become less of a problem.

Disposal and Uses of Harvested Plants

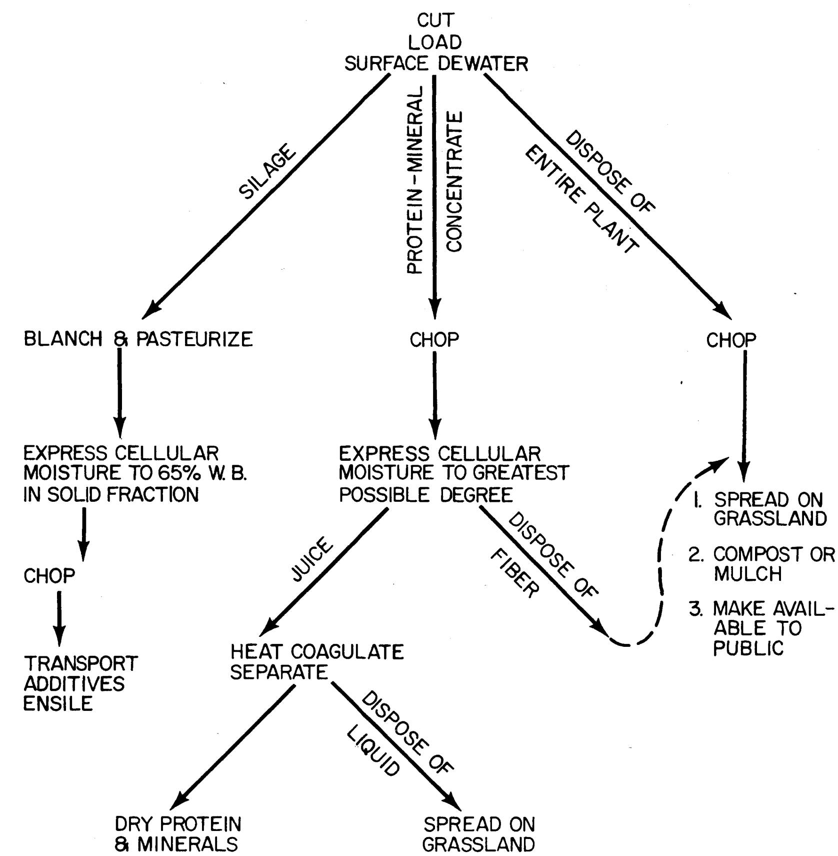
Aquatic plants such as wild rice (*Zizania aquatica*) and cattail (*Typha latifolia*) were used extensively as food by past cultures. The therapeutic values of sweet flag (*Acorus calamus*) have been reported since the time of Hippocrates, and the commercial harvesting of marine plants such as kelp for cattle food, algin, fertilizer, and human consumption is big business not only in North America but also in Europe and Japan.

The very definition of weed indicates that the plant has no commercial value, for if a commercially feasible use for the harvested plant material could be found, a weed would become a natural resource. Researchers are, therefore, exploring the end-product uses of aquatic plants.

The survey (Append. B) indicated that present-day removal and disposal of the plants from the lake depended largely on the type of machine used. Generally, the plants were hauled to local landfill sites or used as compost and mulch on shoreline property.

At the University of Florida researchers have used water hyacinth (*E. crassipes*) for making paper, composting, supplemental soil in muck farming, potting soil, and animal feed. The Hiller process, also developed in Florida, was one of the first attempts at an industrial-type project aimed at the utilization of water hyacinth. The Hiller processor is a portable unit which cuts and dries aquatic plants and puts them in a form suitable for processing in a pellet mill (Vietmeyer 1968). In evaluating the Hiller processor, Bagnall (1970) stated that when operating on water hyacinth, the processor has neither the capacity nor the efficiency to be considered as an economical cattle feed processing system or a full-scale aquatic weed removal system, but does provide a point of departure for development of more adequate systems.

FIGURE 11. *Alternate processing paths for aquatic vegetation (from Koegel et al. 1972).*



Elodea (*Anacharis canadensis*), milfoil (*Myriophyllum exalbescens*) and coontail (*Ceratophyllum demersum*) were harvested from Caddo Lake, Texas and processed through a conventional alfalfa dehydration mill. The product was delivered to Texas A. and M. University for feeding programs involving poultry, swine, and cattle. Because of the high xanthophyll content (0.01 oz/1b [135 mg/kg]) there were indications that it would be marketable as a poultry feed supplement for egg yolk and broiler pigmentation (Lange 1965).

Koegel et al. (1972) at the University of Wisconsin are exploring a variety of processing pathways for aquatic vegetation which utilize numerous portions of the plant (Fig. 11). With their technical assistance and using experimental equipment from the Agricultural Engineering Department, the Dane County operation, starting in August 1972, chopped and pressed lake weeds and gave the residue to citizens for gardening purposes. This provided a politically attractive and real solution to disposal problems. It was so successful that the chopping operation was continued during the 1973 season and modifications were made in the harvesting equipment so the chopping and partial dewatering was done on the lake during the harvesting operation.

Worldwide, the use of aquatic plants as a direct food, a product to be fed to livestock, or a soil conditioner could be a very important means of feeding people in less developed nations, for many of these nations have the severest aquatic weed problems. The worldwide economic uses of aquatic plants, reviewed in Little (1968a), include human food, composting, animal feed, and fiber production.

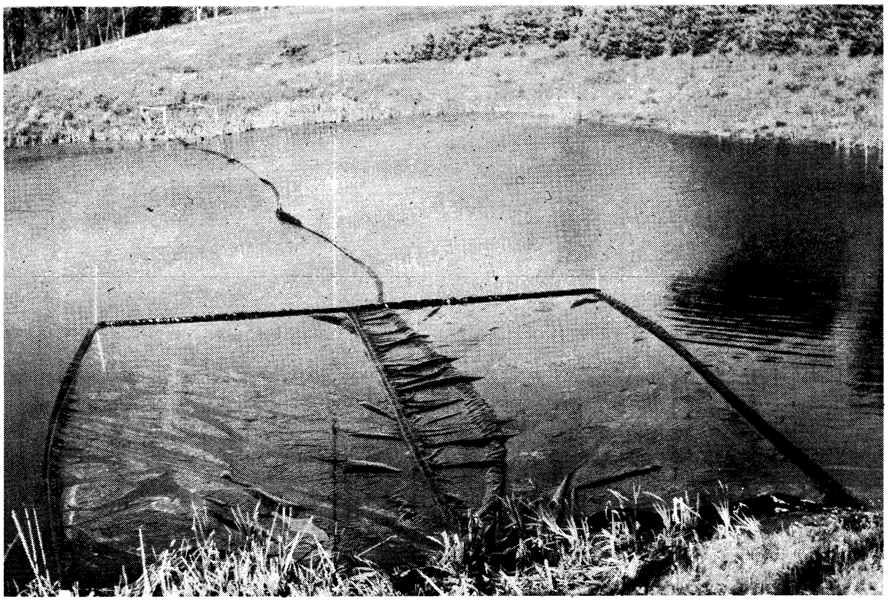
TABLE 2. Typical Harvesting Budget Calculation Sheet*

I.	Capital Investment for Equipment:		
	Harvester	$28,900.00	
	Shore Conveyor	7,200.00	
	Mobilizing Assembly	1,805.00	
	Freight	687.00	
		$38,592.00	
	Annual Depreciation $38,593 ÷ 10 years		$ 3,860.00
II.	Leased Truck and Hauling Expense: 200 miles per day; 5–day week; 66–day season		
	Leasing Fee – $290 x 3 months	$ 870.00	
	Mileage Cost – 200 miles x 66 days x 10¢	1,320.00	
	Gasoline – (200 miles x 66 days x 10 ¢) ÷ 10 mile/gal.	264.00	
			$ 2,450.00
III.	Labor: 8–hour day; 66 days; 2 men @ $4/hour/man (includes fringe benefits)		
	8 hours x 66 days x 2 men x $4/hour		$ 4,224.00
IV.	Harvesting Operating & Maintenance Expense:		$ 1,200.00
V.	Contingencies (10%)		$ 1,162.00
	ANNUAL ESTIMATED OPERATING COST		$12,900.00

	ACRE/SEASON	COST/ACRE
at 1 acre/hour x 8 hours x 66 days	= 528 acre/season	$24.25
at 1/2 acre/hour x 8 hours x 66 days	= 264 acre/season	$48.50
at 1/3 acre/hour x 8 hours x 66 days	= 176 acre/season	$73.00

*Figures provided by Aquamarine Corporation using their equipment.

HABITAT MANIPULATION TECHNIQUES



Black plastic sheeting used as floating shade

The objective of habitat manipulation is to limit plant growth by altering one or more of the physical or chemical factors critical to growth. These critical factors have been previously reviewed in the section headed "Habitat Requirements of Aquatic Plants". The techniques which will be discussed include shading, dredging, sand blanketing, water level manipulation and nutrient limitation.

Shading

The first reported use of dye to limit light penetration was by Eicher (1947). He treated two ponds and two lakes in Arizona with nigrosine dye, and noted a great reduction in visibility after the dye application. The greatest effect of the dye on the rooted aquatics was the year following treatment, when normally semi-emergent weeds failed to surface. Nigrosine was later used, as Bartch (1954) stated, to convert the water into a weak ink, a method he found only partially successful. The dye was nontoxic to fish but had the disadvantage of making the water unattractive until natural forces caused the dye to fade. This method was apparently not popular—there are no reports of its use in recent literature..

More recently Buglewicz (1972) was successful in manipulating plant populations using commercial dyes in eutrophic farm ponds in Nebraska. A new dye has recently been introduced on the market[1]. The Inland Lake Renewal Project has started an evaluation of the product in a Wisconsin farm pond, but presently there are no scientific publications on its effectiveness. The manufacturer states that one gallon will treat an acre (0.4 ha.) of water 5 ft (150 cm) deep; the number of treatments needed depends upon the length of the growing season, water flow rate, fertility, clarity and other factors. For best results, an application early in the season is advised, with retreatment when necessary.

Light penetration was cut off by floating 8 mil black plastic sheeting on top of farm ponds with weed problems in Iowa (Mayhew and Runkel 1962). Good control of pondweeds (*Potamogeton* spp.) and coontail (*Ceratophyllum demersum*) was obtained after 18-26 days of coverage. Experiments to control Chara (*Chara vulgaris*) and emergent species met with failure. A similar project was tested in a Wisconsin farm pond by the Inland Lake Renewal Project and the method completely killed water milfoil (*Myriophyllum exalbescens*) in four weeks.

Dredging

Dredging to depths below the photic zone limits light for plant growth. It can also remove nutrient-rich sediments and alter the textural consistency of the substrate, especially in areas where siltation and sedimentation have covered sterile sand or gravel bottoms. The types of machinery and costs of small-scale dredging operations are reviewed by Pierce (1970). A small dredging project was undertaken at Marion Millpond (Born et al. 1973), consisting of dredging in shallow water to a depth of about 3 ft (1 m) and dredging one area to a depth of 10 ft (3 m). The shallow water dredging appeared to have little utility for plant control; either vascular macrophytes or *Chara* were a continual problem beginning the season after treatment (Fig. 12). Deep dredging does appear to be an effective long-term control technique.

Sand or Gravel Blankets

Blanketing is the process of covering the bottom of a lake or pond with a 6- to 8-inch (15-20 cm) layer of sand or gravel. Sometimes the covering is done over black plastic sheeting. If only a sand or gravel blanket is used, the substrate can be significantly altered. The plastic sheet under the blanket may limit the transport of nutrients from the original lake bottom into the rooting zone of the plants.

Black plastic was used to line drainage and irrigation ditches in Great Britain to control weeds and increase hydraulic capacities (Great Britain, 1959). The method is also recommended for controlling weeds and constructing swimming beaches in farm ponds (Klingbiel et al. 1968).

---

[1]Trade name—Aquashade (R. G. Wilson, pers. com., 1972)

Sand blanket laid over plastic on the ice.

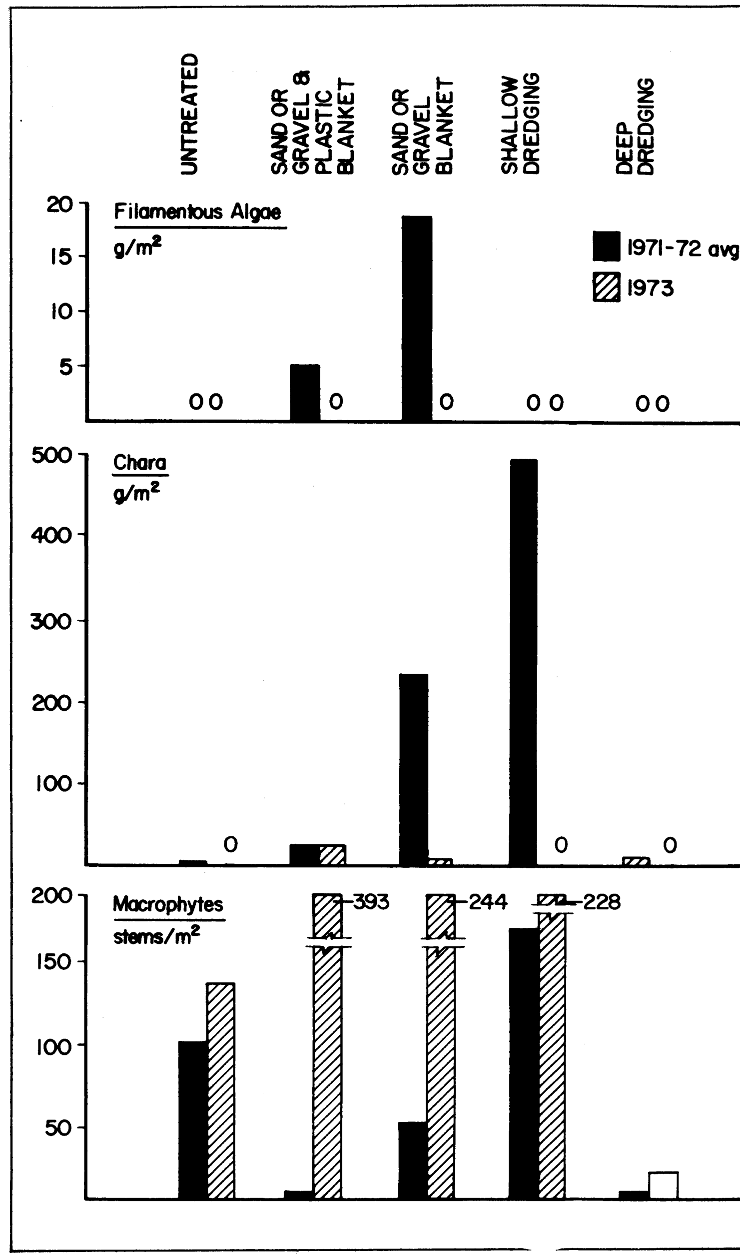


FIGURE 12. *Marion Pond bottom treatment, 1971-1972.*

Winter drawdown.

Two projects were done in Wisconsin, one at Windfall Lake in Forest County and the other at Marion Millpond, Waupaca County. The gravel or plastic blanket at Windfall Lake gave good first-year weed control results, reducing the dry weight biomass of *Chara* from around 810 lbs/acre (1,000 gm/m^2) to virtually nothing. The blanketing also had some beneficial side effects as it provided a spawning area for bluegills and bass, a swimming area with a firm bottom and an area that could be easily maintained free of weeds.

The work on Marion Millpond was considerably more extensive and one should consult Born et al. (1973a) for the details. In addition to dredging, the Marion project included sand blanketing with and without plastic. The averaged results of 1971 and 1972 are compared with the 1973 average in Figure 13. There are considerably more macrophytes on the blanketed areas the third growing season after treatment (1973) than were found the first two seasons. These data certainly raise serious questions about the utility of blanketing for the long-term control of macrophytes.

Overwinter Drawdown

Overwinter drawdown exposes the plants to freezing and desiccation. Frost heaving of large water lily (*Nymphaea* spp. and *Nuphar* spp.) rhizomes appears to be a mechanical control technique resulting from overwinter drawdown. In all cases reviewed both in Wisconsin (Beard 1969, 1973; Nichols 1972, Appendix D) and in southeastern United States (Lantz et al. 1964) drawdown was a very effec-

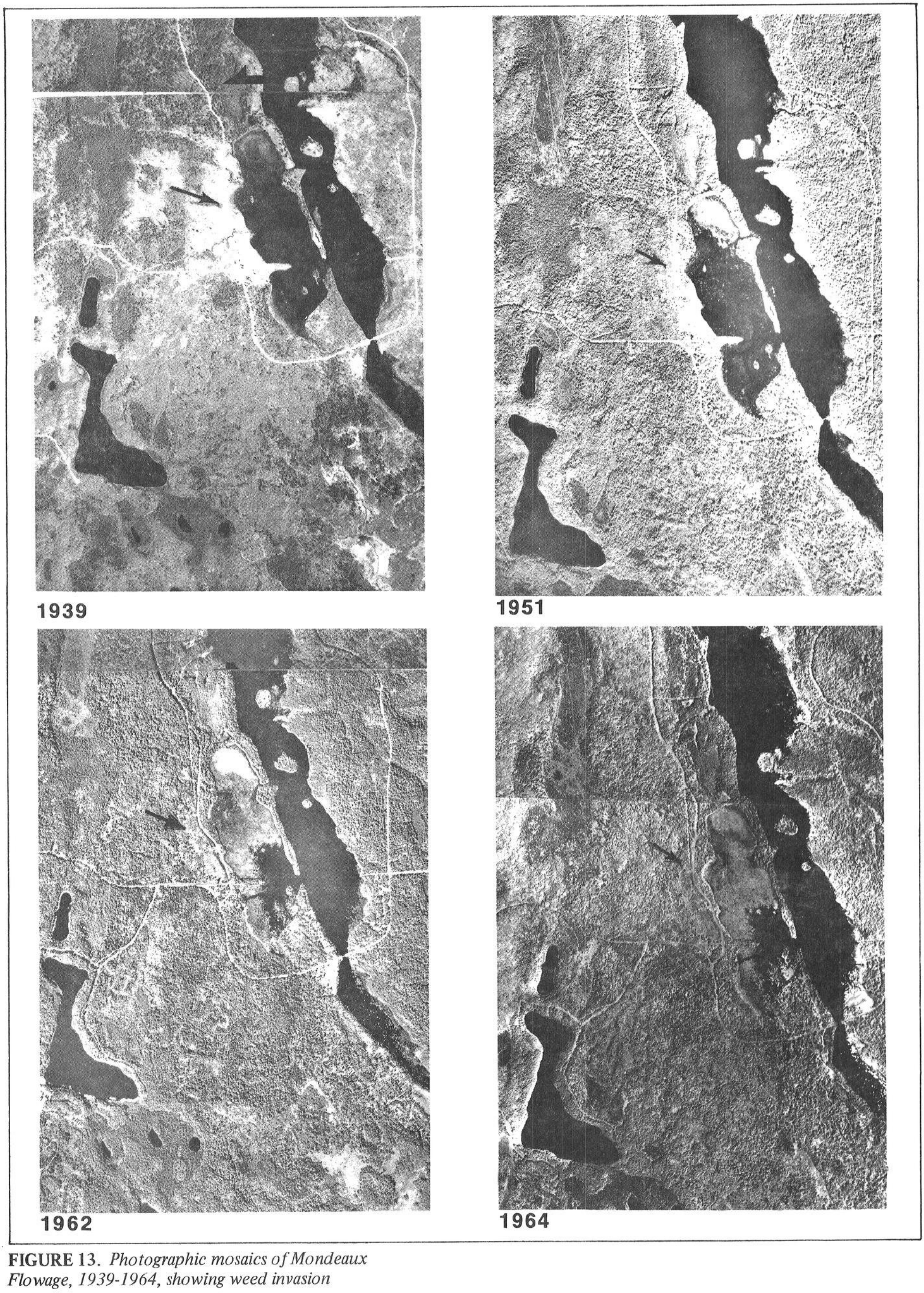


FIGURE 13. *Photographic mosaics of Mondeaux Flowage, 1939-1964, showing weed invasion over time.*

TABLE 3. Influence of Water Fluctuation on Aquatic Plants

Species	Nichols (1972)	Mondeaux Flowage (Append. D)	Beard (1973)	Lantz et al. (1964)
CONTROL BY DRAWDOWN				
Asclepias incarnata (swamp milkweed)	x			
Brasenia schreberi (water shield)	x			x
Ceratophyllum demersum (coontail)		x	x	x
Eleocharis acicularis (spike rush)	x			
Myriophyllum spp. (milfoil)			x	
Nuphar spp. (yellow water lily)	x	x	x	
Nymphaea spp. (white water lily)	x			x
Pontederia cordata (pickerelweed)	x			
Potamogeton amplifolius (large-leaf pondweed)	x		x	
Potamogeton robbinsii (Robbins' pondweed)		x	x	
Potentilla palustris (marsh cinquefoil)	x			
Sagittaria heterophylla (stiff wapato)	x			
Utricularia spp. (bladderwort)	x			x
LITTLE CONTROL BY DRAWDOWN				
Acorus calamus (sweet flag)			x	
Anacharis canadensis (waterweed)			x	
Brasenia schreberi (water shield)			x	
Ceratophyllum demersum (coontail)	x			
Eleocharis acicularis (spike rush)			x	
Lemna spp. (duckweed)			x	
Polygonum coccineum (marsh smartweed)			x	
Potamogeton epihydrus			x	
Potamogeton natans (floating-leaf pondweed)			x	
Potamogeton richardsonii (Richardson's pondweed)			x	
Potamogeton zosteriformes (flat-stemmed pondweed)			x	
Ranunculus tricophyllus (water crowfoot)			x	
Sagittaria latifolia (arrowhead)			x	
Scirpus americanus (three-square bulrush)			x	
Sparganium chlorocarpum			x	
Spirodela polyrhiza (big duckweed)			x	
Typha latifolia (cattail)			x	
Utricularia vulgaris (bladderwort)			x	
Vallisneria americana (wild celery)	x		x	
INCREASE WITH DRAWDOWN				
Acorus calamus (sweet flag)	x			
Glyceria borealis (manna grass)	x			
Leersia oryzoides (cut-grass)	x			
Megalodonta beckii (bur marigold)			x	
Najas flexilis (naiad)	x		x	
Polygonum coccineum (marsh smartweed)	x		x	
Polygonum natans (floating-leaf pondweed)	x			
Potamogeton diversifolius			x	
Potamogeton epihydrous	x			
Potamogeton foliosus (leafy pondweed)	x			
Potamogeton gramineus (variable pondweed)	x			
Potamogeton richardsonnii (Richardsons' pondweed)	x			
Salix interior (sand-bar willow)	x			
Scirpus validus (softstem bulrush)	x			
Sium suave (water parsnip)	x			
Typha latifolia (cattail)	x			

tive and cheap method of weed control.

Drawdown opened over 40 percent of the littoral zone in the Mondeaux Flowage (Append. D). Beard (1973) noted a 70 percent decrease in the acreage covered by aquatic plants in Murphy Flowage. Lantz et al. (1964) reported drawdown as 90 percent effective in removing plants from Anacoco Lake, Louisiana and 50 percent effective on Lafourche Lake, Louisiana. Nichols (1972) reported that the aquatic vegetation probably occupied a lesser absolute area on the Chippewa Flowage, where drawdown has occurred annually for over 50 years, than would be expected under stabilized conditions. There was also a correlation between depth of drawdown on different areas of flowage and differences in aquatic vegetation. Table 3 represents a list of aquatic plants, compiled from the literature, which can or cannot be controlled by drawdown. Although there are slight disagreements among authors, the data are remarkably consistent.

In Sweden a partial overwinter drawdown was used to control plants. The water level was drawn down and the plants allowed to freeze in the ice. Water was then introduced under the ice, which floated the ice mass and mechanically removed the plants (K. Maleug, pers. comm., 1971).

A demonstration was tried at Jyme Lake, Vilas County, Wisconsin to draw down water as a means of sediment consolidation. The effort did not meet with the predicted results, because of conditions peculiar to that lake. But if the method applied could be perfected, it would have the potential of deepening a lake and thus, secondarily, controlling weeds (Smith et al. 1972).

Flooding

Flooding has been most commonly used to control emergent species. A great deal of research took place in the Tennessee Valley Authority Lakes (Penfound et al. 1945; Hall et al. 1946) on the feasibility of using flooding to control the aquatic and semiaquatic plants used by the mosquito *Anopheles quadrimaculatus* for breeding grounds. This mosquito is an important malaria vector in the southeastern states. McDonald (1955) has also shown that increasing water levels is effective in controlling cattails (*Typha latifolia*). The submerged vegetation may also change with increased water depth (Robel 1962), this change probably being most noticeable at the outer edge of the littoral zone.

Nutrient Limitation

The final method for aquatic plant control is nutrient limitation, either through inactivation or dilution. Most methods limit nutrients in the water column, but not in the lake sediments. While these methods could be effective in controlling nonrooted plants, they may or may not be effective against rooted species. Studies by Schults and Malueg (1973) indicated that rooted vascular plants obtain nutrients from both the water column and the sediments, but at differential rates. The methods of nutrient limitation include (a) precipitation of nutrients using materials such as alum, fly ash, or clay; (b) dilution of nutrient-rich waters with nutrient-poor water; and (c) aeration—to retard the release of nutrients from the sediments. Many of these techniques were pioneered in Sweden (Björk 1972) and Wisconsin (Born 1972) and are reviewed by Tenney et al. (1972), and Dunst et al. (in press).

DISCUSSION AND COMPARISON OF METHODS

Any treatment should be assessed using three criteria: (1) cost, (2) results, and (3) ecological implications. These criteria should be considered in light of the objective of the management programs. It should also be realized that most of the treatments suggested here are largely cosmetic; they can offer only immediate relief from the symptoms of the eutrophication problem. Sometimes that is all that can be done. However, it is environmental folly not to attack the source of the problem, whenever possible, even while using these techniques for immediate relief.

Water fluctuation is an effective and inexpensive method of macrophyte control if the problem species are susceptible to drawdown or flooding and if a control structure (generally a dam) exists on the lake. The ecological implications have not been completely analyzed. Small natural lakes can be drawn down with the use of high capacity pumps, but the resulting costs are higher and the potential for negative environmental impacts much greater. The timing of the drawdown is also an important consideration on high use lakes.

Although deep water dredging projects are quite effective in controlling rooted plant growth, few if any are done solely for plant management purposes. If proper planning goes into the project, macrophyte control is a beneficial side effect. Shallow dredging has little utility as a plant control technique. Dredging typically costs about \$0.45 to \$1.00 per cubic yard (0.8 m^3) of material removed and can become prohibitively expensive on a large scale. The negative environmental impacts can be considerable, especially in regard to spoils disposal. Deepening by sediment consolidation would have the same beneficial results as dredging, but the method is largely theoretical at this point.

The advantages and disadvantages of harvesting are most often compared to those of herbicides, since these are the two most common means of plant control. Because of the wide variety of both chemical and harvesting techniques, it is not altogether fair to compare the two; however, some generalities can be pointed up.

Both have the same basic purpose, that is, to manage and control aquatic weeds, generally over short periods of time. Both have approximately the same history of success, from very successful to complete failure, and the cost per acre for both is of the same magnitude and variability (approximately \$15 to \$90 an acre; chemical prices from Karl, 1972).

An advantage of harvesting is that it can remove plants from the lake which, during decay, would deplete the water's dissolved oxygen and release nutrients for new plant growth. Furthermore, harvesting avoids introducing into the ecosystem substantial amounts of chemicals whose full range of effects are poorly understood. This technique is also quite specific to the area in which it is used.

With present technology, harvesting cannot control planktonic algae, and can remove duckweed and filamentous algae only with the use of very specialized equipment, or secondarily, because they cling to large plants that would be the primary target of harvesting. Herbicides can control these problems. In mixed communities, some herbicides are species specific: they will kill certain species of plants and not others. Harvesting removes all the plants in a given area and may take fish or other organisms trapped in the plants. Chemicals, on the other hand, are hard to restrict to a given area. They may drift and affect unintended areas and non-target plants and animals or human water supplies.

Harvesting is said to be slow, but the treated area can be utilized immediately. After the use of herbicides there is a certain period during which the plant must die and decay before the waterway can be opened. With many herbicides it is necessary to place fishing and swimming restrictions on the water after treatment.

Smaller weed cutters and shoreline cleanup units can work in shallow water and around obstacles; thus the argument for using chemicals in shallow water is not necessarily persuasive.

In general, harvesting has beneficial ecological implications because it removes plant material without putting foreign substances into the ecosystem. Harvesting and herbicide treatments are, however, very similar in costs and in the effectiveness of aquatic plant control.

The use of dyes should be considered to be largely in the experimental stages. The older dyes such as nigrosine have been very limited in their use and new dyes have not proven themselves in sufficient trials to warrant wide spread recommendation. The construction of a floating plastic shade costs about $60-$70 for materials to treat one-tenth acre. Its primary utility would be for spot treatment in ponds or around docks and piers. The area directly under the plastic is unusable during treatment.

Sand blanketing also appears to have utility only for treatment of small areas. The cost is large, approximately $275 per acre for plastic sheeting (4 mil.) if it is used, plus local expenses for sand or gravel and labor. Continued maintenance of the area also appears necessary; therefore, areas larger than can be easily maintained should not be treated. Environmentally critical areas, such as wetlands or fish spawning areas, should not be covered.

The costs of nutrient limitation techniques vary so greatly that generalizations are not very useful. While in many cases nutrients are controlled by adding chemicals or other foreign materials to the water system, such treatment is environmentally questionable and should be carefully studied before there is widespread use of such methods. Nutrient limitation techniques have potential for controlling nonrooted plants, but may have little utility for controlling rooted species.

SUMMARY

Management alternatives for aquatic plants fall into four general categories: chemical treatment with herbicides, biological controls, mechanical control and habitat manipulation. This paper deals with the latter two along with the requisite biology and planning procedures necessary to carry out a plant management program. Mechanical control deals with harvesting and removal of aquatic plants from the water. Habitat manipulation includes such considerations as light limitation, water level manipulation, sand and gravel blanketing and nutrient limitation.

Many aquatic plants become weeds because they have high growth and reproductive rates and their environment does not limit this biotic potential. Man wants to manage and many times eradicate these plants because he has found no beneficial uses for them and they hinder his other activities.

In order to design, assess and utilize management techniques, a basic understanding of the biology of the aquatic plant and the habitat in which they grow is necessary. Species identification, growth patterns and distribution of plants are important information for any management program. Some management techniques are more suitable for one plant species than another and are more easily used in certain types of areas. Aquatic plant anatomy is paricularly relevant to harvesting because it makes cutting more difficult but pickup possibly easier than conventional agricultural crops and habitat is also an important consideration for habitat manipulation techniques.

With regard to mechanical harvesting, there is a wide range of equipment available; users must carefully choose a machine or method that will best suit their particular needs. Six companies are identified which presently manufacture harvesting equipment. Literature reviews indicate that intensive mechanical removal programs can significantly reduce the plant biomass not only during the year of harvesting but possibly in subsequent years.

A survey was conducted which identified 32 locations in the upper Midwest where mechanical harvesting was used. In general, it appears that close records were not kept of the costs or acreage harvested. The high initial investment in machinery is probably the most serious obstacle to implementing a management program. Costs varied from about $15 per acre to $75 per acre for a harvesting operation. Presently disposal is an additional cost in a mechanical removal program; however, research is investigating commercial uses of harvested plant materials.

Mechanical removal of plants not only allows for immediate use of the harvested area but the plants removed from the water are not available to deplete dissolved oxygen supplies and release nutrients for new plant growth. The amount of nutrients removed can be substantial in intensively managed areas, but may not have a significant impact on the nutrient budget of a lake unless there is a high biomass of plants in relation to the volume of the lake and the amount of incoming nutrients.

The habitat manipulation techniques reviewed included: shading with dyes and black plastic sheeting, dredging, sand or gravel blanketing, overwinter drawdown, and nutrient limitation. Of these techniques, dredging to a depth below the photic zone is a very effective but costly control. For treatment of large areas, where water control structures exist, overwinter drawdown is a very effective and cheap method for controlling certain species. Black plastic sheeting floating on top of the water shaded out plants in three to four weeks, but is generally applicable only to a small area. Sand or gravel blanketing showed initially encouraging results, but the treatment appeared to be short lived unless the area could be further managed.

The use of dyes and nutrient limitation techniques give rather inconclusive results in regard to plant control. It would appear that nutrient limitation techniques have more applicability for controlling algae than macrophytes.

Most of these tecniques, whether they be harvesting or habitat manipulation, treat only the symptoms of eutrophication problems. At worst, this is all that can be done; at best, they can be used as stop-gap measures while correcting the underlying causes of the problem.

APPENDIXES

A: Survey Questionnaire

1. The location of the harvesting operation
2. Who paid for and conducted the operation (local unit of government, lake property owners' association, individuals?)?
3. The type of machine used
4. The cutting capacity of the machine (width of the cutting bar and depth to which it can cut)
5. The maximum efficiency at which the machine can cut (i.e., acres/hour)
6. The type of weed problem (i.e., problem species)
7. The number of acres harvested per year
8. The number of times harvested per year
9. The number of continuous years the area has been harvested
10. The cost per year of harvesting
11. If and how the plants are removed from the lake
12. The location and means of disposal of plant material
13. The noticeable effects, either beneficial or detrimental and long or short term, of the harvesting operation

B: Survey of Harvesting Experiences

Name of Lake	Location	Who Paid	Type of Machine	Type of Weed Prob.	Total # Acres/Year	#Times/Year	#Cont. Years	Removal of Plants	Disposal	Cost/Year	Benefit
	WISCONSIN										
Browns Lake	Burlington	Sanitary Dist.	Grinwald Thomas	?	300 (120 ha)	2	2	Loaded on harvester	Dump	$5,909.82 + $30,000 for harvester	Short-term
Buffalo	Montello	Prop. Owners Assoc.	Aquatic Controls Dugong	Coontail Cattail Water Lily	?	1	2	Rake	Landfill	$25/A	Long-term
Clam Lake	Siren	Sportsmans Club	Hockney	Curly leaf Pondweed	Varies with need	2	11	Windblown to shore	Mulch	Contract work $6/hr.	Short-term
Dane Co. Lakes	Dane Co.	County	Grinwald Thomas & Aquamarine Amer. Waterweed	Milfoil & filamentous algae	3,500 (1,400 ha)	3–4	3	Loaded on harvester	Dump	$35,000 operational exp. $45,000 capital outlay	Short-term
Dept. of Nat. Res. Warm Water Rearing Pond	Madison	State	Aquamarine Sawfish	Coontail & Elodea	10 (4 ha)	1	1	Rake on cutter	Compost on shore	?	Short-term
Lac La Belle & Fowler Lakes	Oconomowoc	City	Grinwald Thomas	Milfoil	98 (40 ha)	3	5	Loaded on harvester	Mulch	$3,800	Short-term
Lakes in Milwaukee Co. Park System	Milwaukee Co.	County	Grinwald Thomas	Wide Variety	180 (72 ha)	2 or 3	3	Loaded on harvester	Composting Center	$8,700	Short-term
Lily Lake	Burlington	Prop. Owners Assoc.	Hockney	Pondweed, Chara, Najas,	40 (16 ha)	2	20	Raked to shore	Mulch	$2,500	Short-term
Little Butternut	Luck	Individual	Hockney	Coontail	1 (0.4 ha)	5	5	Raked to shore	Mulch	?	None
Little Green	Markesan	Lake Improvement Assoc.	Ben H. Anderson	?	50 (20 ha)	1–2	3	Raked to shore	Mulch	$300	Short-term
Little St. Germain	Vilas Co.	Prop. Owners Assoc.	Hockney	Musky Weed, Duckweed	60 (24 ha)	Continuous June & July	4	Raked to shore	Mulch & Dump	Gas? Labor free	Long-term
Lower Phantom	Mukwonago	Lake Improvements Org.	Hockney	Pondweed, Chara & Others	32 (13 ha)	2	9	Rake	Mulch	$150	Cut floating weeds caused problem
Nagawicki	Delafield	City	Grinwald Thomas	Milfoil & algae	250 (100 ha)	2	4	Loaded on harvester	Dump & Mulch	$6,500 operational $4,000 capital outlay	Short-term

Name of Lake	Location	Who Paid	Type of Machine	Type of Weed Prob.	Total # Acres/Year	#Times/Year	#Cont. Years	Removal of Plants	Disposal	Cost/Year	Benefit
Okauchee Fowler Upper Oconomowoc Lake La Belle	Oconomowoc	Town & City of Oconomowoc	Grinwald Thomas	Milfoil, Wild Celery	2,000 (800 ha)	1–2	9	Loaded on harvester	Mulch & Dump	For town of Oconomowoc $5,000–$5,500	Short-term
Park Lake	Pardeeville	Co. & Vill.	Marine Scavenger	Coontail & Pondweed	40 (16 ha)	1	2	Loaded on harvester	Mulch or Cropland	$2,000	Short- and long-term
Pewaukee	Pewaukee	Sanitary Dist.	Grinwald Thomas	Eurasian Milfoil	?	Varied	24	Loaded on harvester	Landfill	$20,000	Short-term
Rib	Rib Lake	Vill.	Marine Scavenger	Wide Variety	640 (336 ha)	2	5	Loaded on harvester	Mulch	?	Long-term
Rice	Rice Lake	City & Town Gov.	Grinwald Thomas	Wide Variety	30–40 (12–16 ha)	2	6	Loaded on harvester	Compost	$3,064	Short-term
Spring Lake	Palmyra	Vill.	?	Variety	13 (5 ha)	Once	2	Loaded on harvester	Vill. dump	$700	Short-term
Sturgeon Bay, Lake Michigan	Sturgeon Bay	City	Custom built	?	?	3–4	3	Hand when drifted to shore	Land owners disposed individually	$5,000 cost of machine, $1,862 labor $374.63 maintenance	Long-term
Lake Wandawega	Elkhorn	Wandawega Country Club	Dugong	?	50 (20 ha)	12	10	Raked to shore	Burning & mulch	Gas & oil & repair prop. owners do work gratis	Short-term
Wilson	Waushara Co.	Spring Water Improvement Assoc.	Manette "45" Dynamic controls (Aquatic controls)	?	2–3 (0.8–1.2 ha)	1–2	4	Pushed to shore with rake	Mulch	Gas & oil	Short-term
Windfall Lake	Wabeno	Prop. Owners Assoc.	Aquatic Controls Manette "45"	Elodea, Chara Coontail Milfoil	3 (1.2 ha)	3–4	2	Rake on cutter; many left in lake	Dump	$150/A	Detrimental Seen to have spread the problem
Wingra	Madison	Lake Wingra Boat Rental	Dugong	Water Milfoil	?	3–4	5	Hand pitch fork	Landfill	Donated gas & labor	Short-term
	MICHIGAN										
Tamarack	Lakeview	Lake Assoc.	Marine Scavenger	Wide Variety	100 (40 ha)	2	2	Loaded on harvester	Dump	$3,500	Long-term
Victoria	Laingsburg	Prop. Owners Assoc.	Hockney HC=10	Coontail Pondweed Milfoil	25 (10 ha)	1–5	2	Hand pitch fork	Compost	$3,000	Short-term
	MINNESOTA										
Lake Sallie	Minnesota	EPA & Pelican River Watershed Assoc.	Aquatic Controls	Milfoil Celery Narrow leaved Pondweeds	400 (160 ha)	Continuous during summer	2	Loaded on harvester	Spread on farmland	$13,500	Short, but possible long-term result

C: Mechanical Control of Aquatic Plants in Minnesota, 1971*

Lake	County	Acres**
Big Sandy	Aitkin	0.12
Minnewawa	Aitkin	2.75
Pine, Big	Aitkin	0.69
Rock	Aitkin	1.00
Wilkins	Aitkin	0.08
Coon	Anoka	20.65
Sallie	Becker	400.00
Julia	Beltrami	0.68
Black Duck	Beltrami	0.05
Sleepy Eye	Brown	27.54
Gull	Cass	0.06
Poquet	Cass	1.38
Green	Chisago	0.12
Bay	Crow Wing	0.92
Clark	Crow Wing	65.00
Little Hubert	Crow Wing	0.10
Little Pine	Crow Wing	2.00
Long, North	Crow Wing	0.23
Long, South	Crow Wing	0.57
Crystal	Dakota	0.50
Burgen	Douglas	0.06
Mary	Douglas	1.22
Rice	Faribault	0.46
Black	Hennepin	3.45
Christmas	Hennepin	1.55
Minnetonka	Hennepin	47.31
Round	Hennepin	3.67
Sarah	Hennepin	0.02
Weaver	Hennepin	10.00
Island	Hubbard	0.37
Big Mantrap	Hubbard	2.00
Portage	Hubbard	0.04
West Crooked	Hubbard	0.18
Spectacle	Isanti	0.15
Bowstring River	Itasca	0.32
Big Split Hand	Itasca	1.38
Nest	Lake	0.09
Lizzie	Otter Tail	1.15
Pine, Big	Otter Tail	2.30
Rush	Otter Tail	1.38
Island	Pine	0.92
Minnewaska	Pope	0.25
Bald Eagle	Ramsey	0.23
Silver	Ramsey & Anoka	2.30
Vermilion	St. Louis	13.77
Ann	Sherburne	0.05
Brown	Stearns	0.32
Clearwater	Stearns	0.18
Koronis	Stearns	0.46
Beauty	Todd	1.30
Big Birch	Todd	0.23
Swan	Todd	1.55
Osakis	Todd & Douglas	0.10
Sauk	Todd & Stearns	11.00
De Montreville	Washington	0.23
Bass	Wright	0.05
Charlotte	Wright	0.06
Howard	Wright	1.31
John	Wright	0.23
Sylvia	Wright	0.09
	Total	636.17

	1969	1970	1971
Number of lakes in which control was permitted	31	25	60
Acres of water on which control was accomplished by harvesting	224	548	636

*From Bonnema, K and W. Johnson, 1971.
**Permit required for mechanical removal of plants in area larger than 2,500 ft.^{2}.

D: The Use of Overwinter Drawdown on the Mondeaux Flowage

With the background information on the long-term impacts of overwinter drawdown (Beard 1969 and Nichols 1972), the method was subjected to further field evaluation at the Mondeaux Flowage, Taylor County, Wisconsin. The Flowage was constructed as a recreational flowage in 1938. Over its 34-year existence as a stabilized flowage, aquatic vegetation became so dense during summer months that normal fishing and boating activities were curtailed. The problems have become particularly acute since 1963 (Fig. 14). Several conditions made it an ideal location for further testing: a long history of weed problems, a depth of under 3 ft (1 m) over 22 percent of its 416 acres (166 ha) (Fig. 14), and the fact that water level could be regulated. The project was a cooperative effort between the U.S. Forest Service, the Department of Natural Resources, and the Inland Lake Renewal Project.

METHODS

To assess the impact of drawdown on aquatic vegetation, two sampling techniques were used. The frequency of species occurrence was obtained by taking random rake grabs in transects paralleling the shore. These transects were lumped into three depth intervals: 0-1.5 ft (0-0.5 m), 1.5-4.5 ft (0.5-1.5 m), and 4.5-7.5 ft (1.5-2.5 m). Thirty grabs of approximately 1 ft^2 (0.1 m^2) were taken in each depth class and the frequency was calculated as the percentage of times each species was collected. The transects were confined to the southern half of the flowage.

Four permanent plots were located in the flowage to sample density (Fig. 14). Point A was placed at 1.5 ft (0.5 m), Point B at 6 ft (2.0 m), Point C was over 7.5 ft (2.5 m) and Point D at 3 ft (1.0 m). The plots were marked using steel fenceposts, and ten 1 ft^2 (0.1 m^2) quadrats were sampled randomly, with the aid of SCUBA techniques, within a 10 ft (3 m) radius of each stake. The number of stems of each species in each quadrat was counted as the measure of density. A wild rice bed in the northern part of

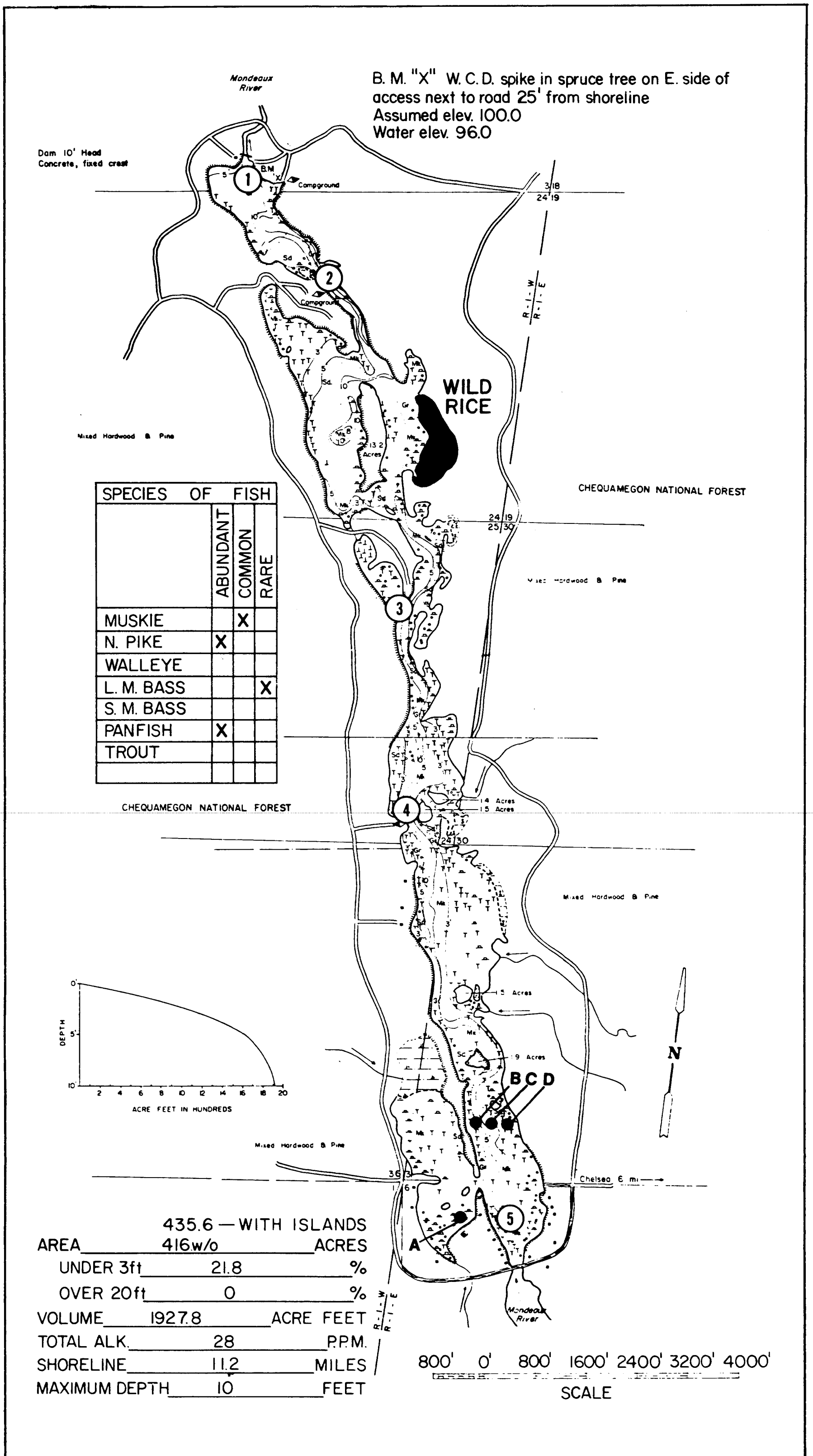


FIGURE 14. *Map of Mondeaux Flowage showing sampling locations.*

the flowage was also sampled using ten 1 ft^2 (0.1 m^2) plots.

In addition, inlet and outlet water flow data were recorded and water sampled for chemical analysis during the 1972 growing season. Department of Natural Resources personnel checked winter water quality during the 1971-72 season to ascertain if the low water conditions might have an adverse effect on the fisheries.

TABLE 4. Species List for the Mondeaux Flowage

Anacharis canadensis – elodea
Brasenia schreberi – water shield
Ceratophyllum demersum – coontail
Eleocharis acicularis – slender spikerush
Lemna minor – duckweed
Lemna trisulca – star duckweed
Myriophyllum heterophyllum – broadleaf water milfoil
Najas flexilis – naiad
Nuphar variegatum – yellow water lily
Nymphaea tuberosa – white water lily
Polygonum coccineum – marsh smartweed
Polygonum natans – water smartweed
Potamogeton americanus – American pondweed
P. amplifolius – largeleaf pondweed
P. filiformes
P. gramineus – variable pondweed
P. natans – floating leaf pondweed
P. pectinatus – sago pondweed
P. robbinsii – Robbin's pondweed
P. zosteriformes – flatstem pondweed
Sagittaria latifolia – arrowhead
Sagittaria sp. – arrowhead
Typha latifolia – cattail
Utricularia vulgaris – bladderwort
Zizania aquatica – wild rice
Drepanocladus sp. – aquatic moss

FIELD PRACTICES AND RESULTS

The flowage was first sampled during August 1971 to obtain data on the aquatic vegetation before drawdown. The macrophyte species were identified (Table 4) and the density and frequency of the common species recorded (Tables 5, 6 and 7).

The gates were opened on the dam on October 4, 1971. A drawdown of 58 inches (145 cm) was obtained by October 29 so that a great deal of the shallow water zone was exposed early in the winter (Fig. 15).

An assessment of the winter fish habitat in the flowage was made by Department of Natural Resources personnel and no visible evidence of winterkilled fish was found. Dissolved oxygen data indicated that there was a slightly greater oxygen supply under drawdown conditions than under stabilized conditions (Table 8).* This would seem to indicate that there is less of a chance for winterkill of fish or other aquatic organisms under drawdown conditions than under stabilized conditions.

The Flowage was subjected to a similar drawdown during the 1972-73 winter, but the water quality and water flow data were not as closely monitored.

The primary reason for sampling water quality and flow was to determine if there was any great flush of nutrients, particularly nitrogen and phosphorus, which might at least in part be attributed to decaying plants. Although the concentrations of nutrients dropped (Figs. 16, 17 and 18) during the spring flood, the total output of nitrogen and phosphorus was manyfold greater, especially during the third week of April (Fig. 19). Since there were no nutrient data from previous years, and since the flush of nutrients in the spring is a natural occurrence (Lee et. al. 1970) the proportion of nitrogen and phosphorus attributable to decaying plants cannot be assigned. It is interesting to note that by the time the recreation season starts (about June 1), the incoming phosphorus and nitrogen levels are higher than the outgoing concentrations. Concentration ranges of other nutrients samples are given in Table 9.

The vegetation analysis shows that both the frequency and density of the problem aquatic plants were reduced. The frequency data (Table 5) were analyzed using a Chi-square (X^2) test, with the expected values being the frequency found in August, 1971. This assumption is valid, as Natleson (1954) found that the frequency of aquatic plants in a stand varied only slightly over the growing season. Of the species with a frequency of over 10 percent, only *Polygonum natans* showed no significant decrease as indicated by frequency data. These data also indicated that slightly over 43 percent of the littoral zone was open in 1972, compared to none in 1971 (Fig. 20).

Density data (Table 7) also indicated a significant decrease in plant abundance. Areas where densities ranged from over 110 stems/m^2 in 1971 had 33 or less stems/m^2 in 1972. Point C was the exception to this statement; it was, however, located on the outer edge of the littoral zone and had few plants to begin with.

There were no drastic differences in frequency or density of species between 1972 and 1973.

The impact on the wild rice (Table 7) appeared to be minimal. In originally proposing this project, concern was expressed about the impact of drawdown on wild rice, because of its sensitivity to fluctuating water conditions (Dore 1969).

*Personal communication, Gerry Bever, Area Fish Manager.

TABLE 5. Frequency of species occurrence in the Mondeaux Flowage (Percent) according to water depth

Species	August 1971	June 1972	July 1972	August 1972	August 1973	X^2
Water Depth 0–1.5 ft. (0–0.5 m)						
Potamogeton robbinsii	93.3	10.0	20.0	26.7	23.3	179.5**
Ceratophyllum demersum	46.7	30.0	20.0	53.3	30.0	22.16**
Nuphar variegatum	43.3	16.7	33.3	23.3	10.0	27.88**
Nymphaea tuberosa	16.7	3.3	6.7	3.3	6.7	27.49**
Polygonum natans	16.7	10.0	20.0	16.7	0	3.34
Potamogeton amplifolius	10.0	0	0	0	0	30.0**
Potamogeton pectinatus	6.7	0	0	0	0	20.10**
Anacharis canadensis	3.3	0	3.3	3.3	0	3.3
Polygonum coccineum	3.3	0	0	0	3.3	9.9**
Brasenia schreberi	3.3	3.3	0	6.6	0	3.3
Najas flexilis	0	0	3.3	0	0	N.M.P.
Sagittaria sp.	0	0	0	0	6.7	–
Potamogeton natans	0	0	0	0	3.3	–
Potamogeton filiformes	0	0	0	0	3.3	–
Myriophyllum heterophyllum	0	0	0	0	3.3	–
Open	0	56.7	20.0	20.0	36.7	N.M.P.
Water Depth 1.5–4.5 ft. (0.5–1.5 m)						
Potamogeton robbinsii	96.7	26.7	30.0	40.0	60.0	129.93**
Ceratophyllum demersum	26.7	6.7	16.7	43.3	16.7	29.05**
Nuphar variegatum	3.3	0	0	0	0	–
Anacharis canadensis	10.0	0	0	0	0	30.00**
Utricularis vulgaris	0	0	3.3	0	0	N.M.P.
Open	0	73.3	63.3	30.0	33.3	N.M.P.
Water Depth 4.5–7.5 ft. (1.5–2.5 m)						
Potamogeton robbinsii	93.3	83.3	30.0	33.3	40.0	82.6**
Ceratophyllum demersum	86.7	10.0	20.0	23.3	30.0	165.5**
Anacharis canadensis	3.3	0	0	0	0	–
Potamogeton gramineus	3.3	0	0	0	0	–
Open	0	6.7	56.7	63.3	36.7	N.M.P.

N.M.P. – Not mathematically possible.
**August, 1971 frequency significantly different from 1972 frequency at 0.95 using a Chi-square test.

TABLE 6. Frequency and Relative Frequency of Species Occurrence, Mondeaux Flowage

Species	Total Frequency (Percent) 1971	1972	1973	Relative Frequency (Percent) 1971	1972	1973
Potamogeton robbinsii	94.4	33.3	41.1	50.0	28.1	40.0
Ceratophyllum demersum	53.3	24.8	25.5	28.2	20.9	22.3
Nuphar variegatum	15.6	8.1	3.3	8.2	6.8	2.9
Nyphaea tuberosa	5.6	1.5	2.2	2.9	1.3	1.9
Polygonum natans	5.6	5.2	0	2.9	3.7	0
Potamogeton amplifolius	3.3	0	0	1.8	0	0
Potamogeton pectinatus	2.2	0	0	1.2	0	0
Anacharis canadensis	5.6	0.7	0	2.9	0.6	0
Polygonum coccineum	1.1	0	1.1	0.6	0	1.0
Brasenia schreberi	1.1	1.1	0	0.6	0.9	0
Potamogeton gramineus	1.1	0	0	0.6	0	0
Najas flexilis	0	0.4	0	0	0.3	0
Sagittaria sp.	0	0	2.2	0	0	1.9
Potamogeton natans	0	0	1.1	0	0	1.0
Potamogeton filiformes	0	0	1.1	0	0	1.0
Myriophyllum heterophyllum	0	0	1.1	0	0	1.0
Open	0	43.3	35.6	0	36.6	31.1

TABLE 7. Mean Density of Species at Permanent Plots in Mondeaux Flowage (stems/1 ft^2 [0.1m^2] ± 95%)

POINT A 1.5 ft. (0.5m) Deep	Aug. '71	June '72	July '72	Aug. '72	Aug. '73
Potamogeton robbinsii	3.1	0	0	0	0.1
Ceratophyllum demersum	1.1	0	0	0	1.8
Nuphar variegatum	3.1	0.9	0.8	0.7	1.4
Polygonum natans	1.6	1.2	2.8	3.4	0
Potamogeton pectinatus	0.1	0	0	0	0
Anacharis canadensis	0.5	0	0	0	0.6
Brasenia schreberi	1.7	0	0	0	0
Utricularia vulgaris	0	0	0	0	0.4
Potamogeton filiformes	0	0	0	0	1.1
Nymphaea tuberosa	0	0	0	0	0.7
	11.2±3.6	2.1±1.3	3.6±3.2	4.1±1.1	6.1±3.4
Grand mean–1972	3.3±1.1**				
POINT B 6 ft. (2.0m) Deep					
Potamogeton robbinsii	11.1	0	0.5	2.3	4.3
Ceratophyllum demersum	1.1	0	0	0.6	0.7
Polygonum natans	0.1	0	0	0	0
Potamogeton amplifolius	0.1	0	0	0	0
	12.4±7.8	0	0.5±0.9	2.9±2.2	5.0±2.1
Grand mean–1972	1.1±0.7**				
POINT C 7.5 ft. (2.5m) Deep					
Potamogeton robbinsii	0	0.4	0	0.7	0
Ceratophyllum demersum	0	0.3	0	0.2	0
	0	0.7±0.2	0	0.9±1.1	0
Grand mean–1972	5±0.8				
POINT D 3 ft. (10m) Deep					
Potamogeton robbinsii	12.9	0.2	0.2	0.1	0
Ceratophyllum demersum	0	0	0.1	0.3	0.3
Nuphar variegatum	0	0	0.0	0.1	0
	12.9±1.8	0.2±0.3	0.3±0.3	0.5±0.5	0.4±0.7
Grand mean–1972	0.3±0.8**				
Wild Rice	13.6±2.6			13.7±2.6	19.7±4.8

**Grand mean–1972 significantly different than August 1971 mean at 0.95 using a Student's t–test.

TABLE 8. Oxygen Conditions in Mondeaux Flowage 1971–72

	Dissolved Oxygen (ppm)				
Date	1*	2	3	4	5
29 Nov. 1971	10.8	11.0	–	–	11.2
15 Dec. 1971	6.2	8.5	–	–	–
6 Jan. 1972	3.6	–	–	–	–
10 Jan. 1972	1.5	2.5	6.8	8.1	10.4
18 Jan. 1972	0.7	2.9	6.8	8.5	10.8
1 Feb. 1972	4.2	6.0	6.5	8.1	–
9 Feb. 1972	4.9	–	7.3	–	–
14 Feb. 1972	4.0	8.8	–	7.0	–
29 Feb. 1972	4.8	–	–	–	–
7 Mar. 1972	6.8	–	–	–	–
9 Mar. 1972	6.7	–	–	–	–
14 Mar. 1965	2.0 (3 ft.) 1.1 (5 ft.)		6.3 (3 ft.) 5.4 (5 ft.)		10.5

*Locations given on Figure 14.

TABLE 9. Concentration Ranges of Nutrients in Mondeaux Flowage (mg/1)

Nutrient	Low Value	High Value
Ca	3.5	19.0
Mg	2.3	7.0
Na	<0.1	3.7
K	0.3	1.8
SO_4	5.0	11.0
Cl	2.0	4.0
Alkalinity (mg/1$CaCO_3$)	9.0	46.0

FIGURE 15. *Drawdown curve for Mondeaux Flowage, winter, 1971-1972.*

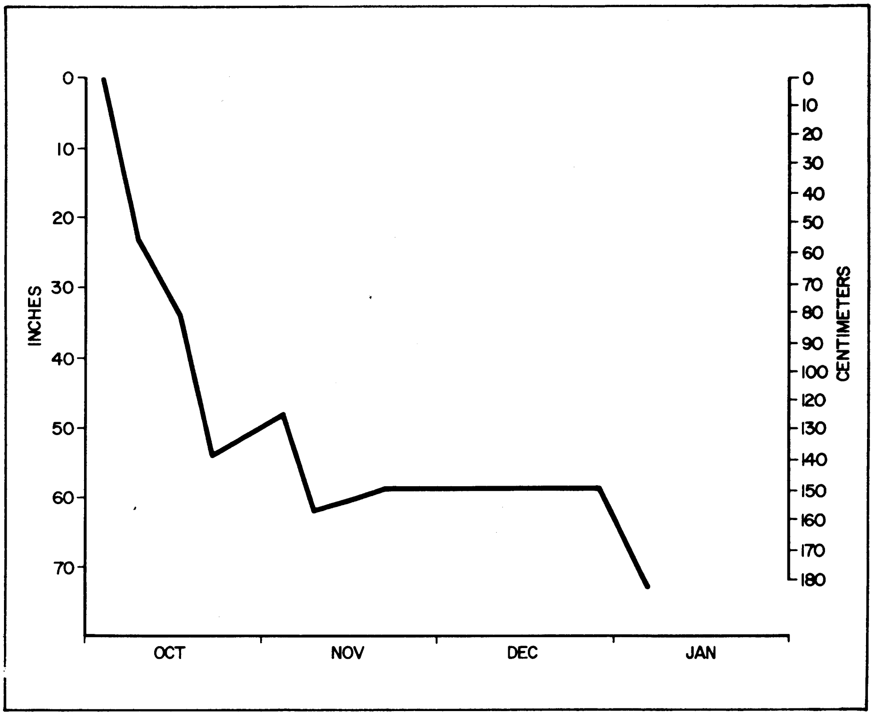
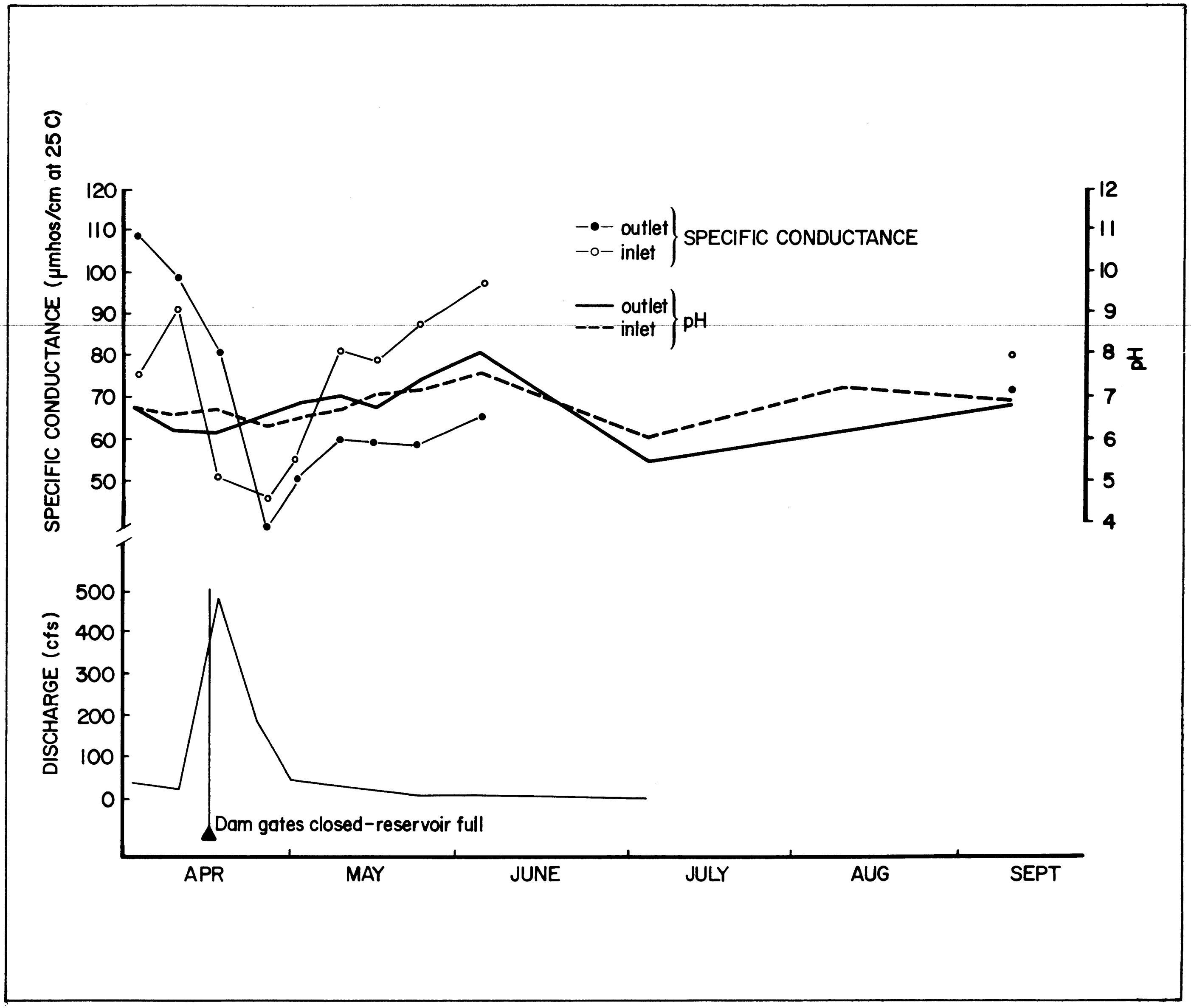


FIGURE 16. *Specific conductance and pH of Mondeaux Flowage water, growing season, 1972.*



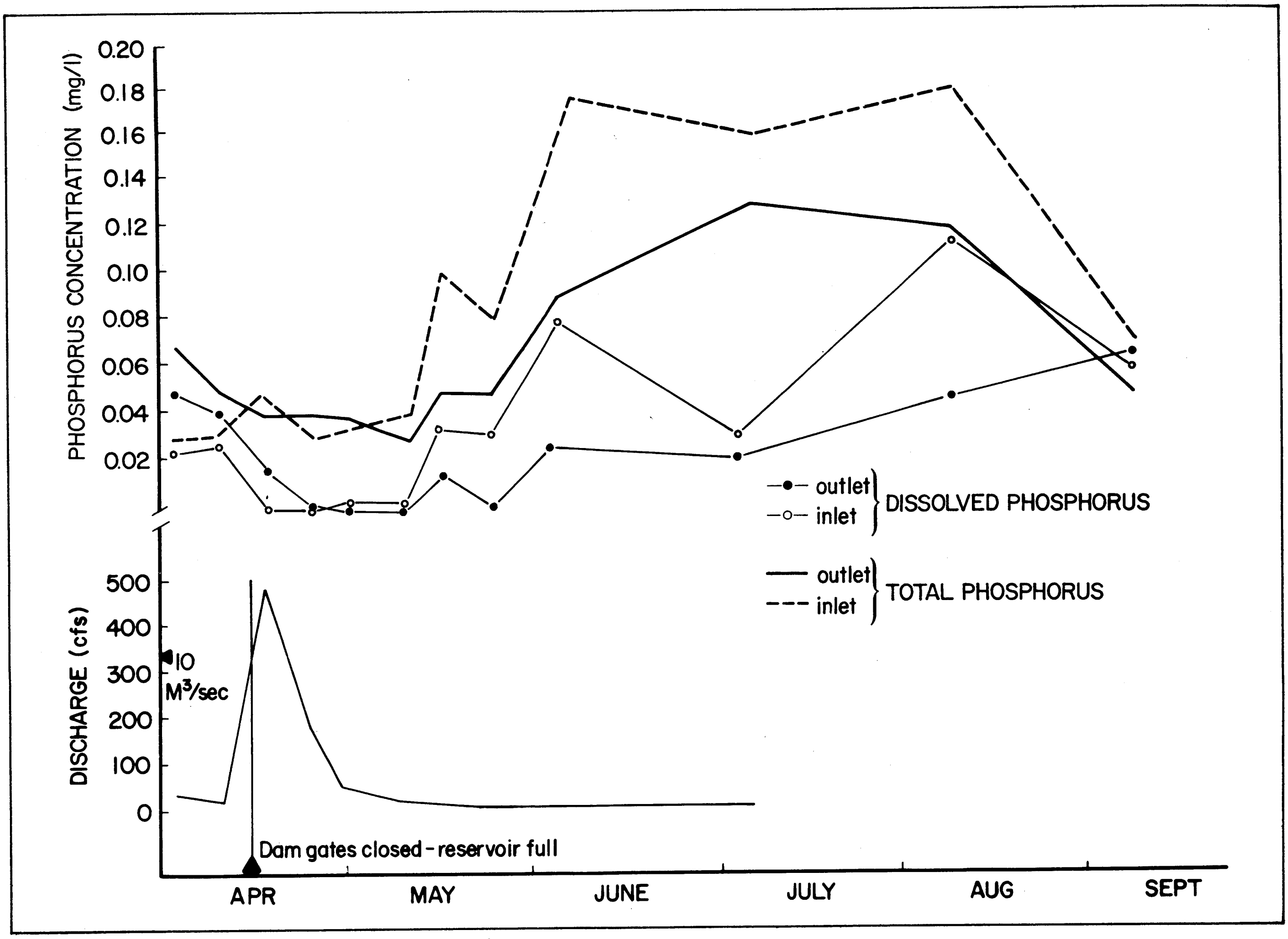
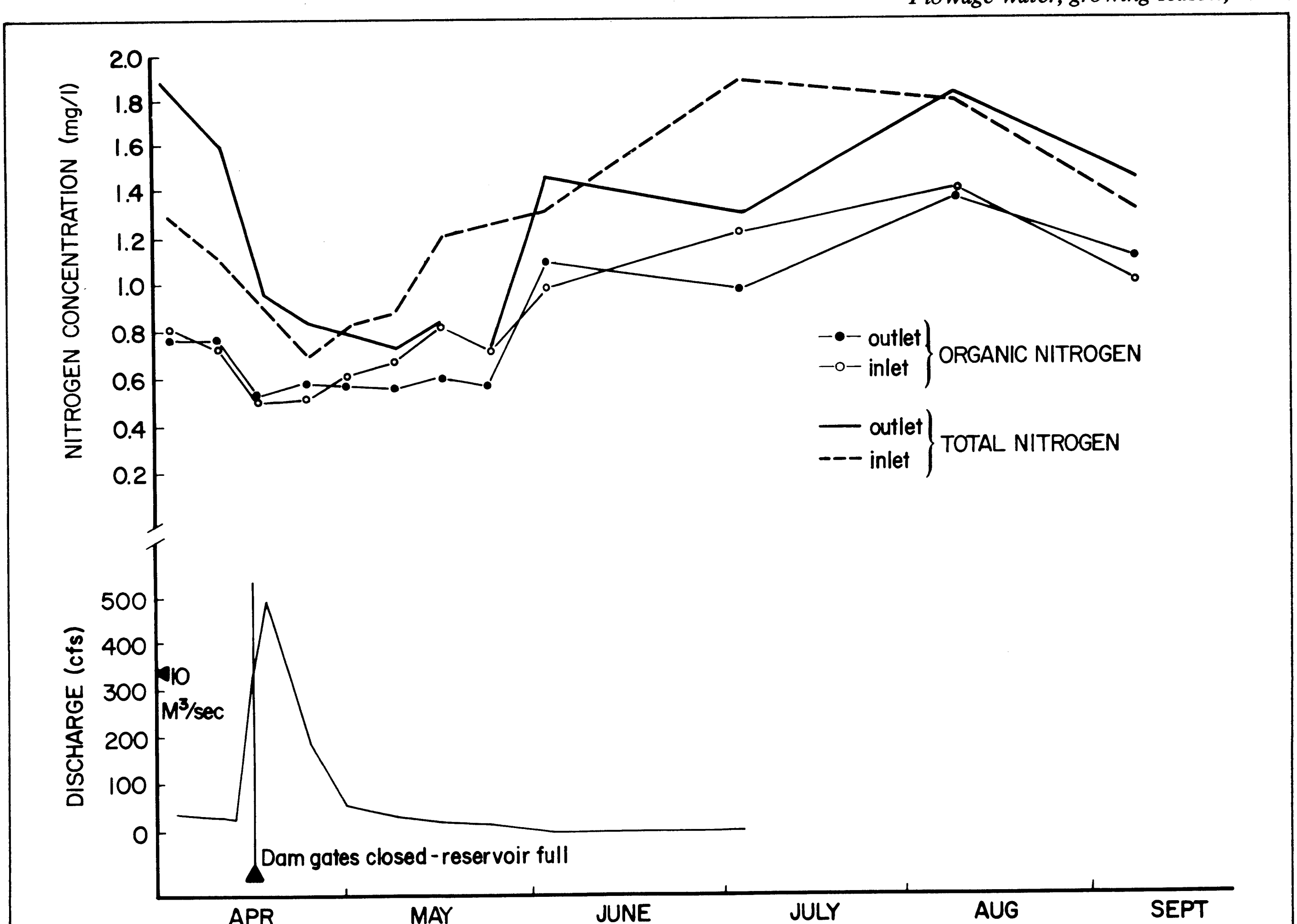


FIGURE 17. *Phosphorus concentration, Mondeaux Flowage water, growing season, 1972.*

FIGURE 18. *Nitrogen concentration, Mondeaux Flowage water, growing season, 1972.*



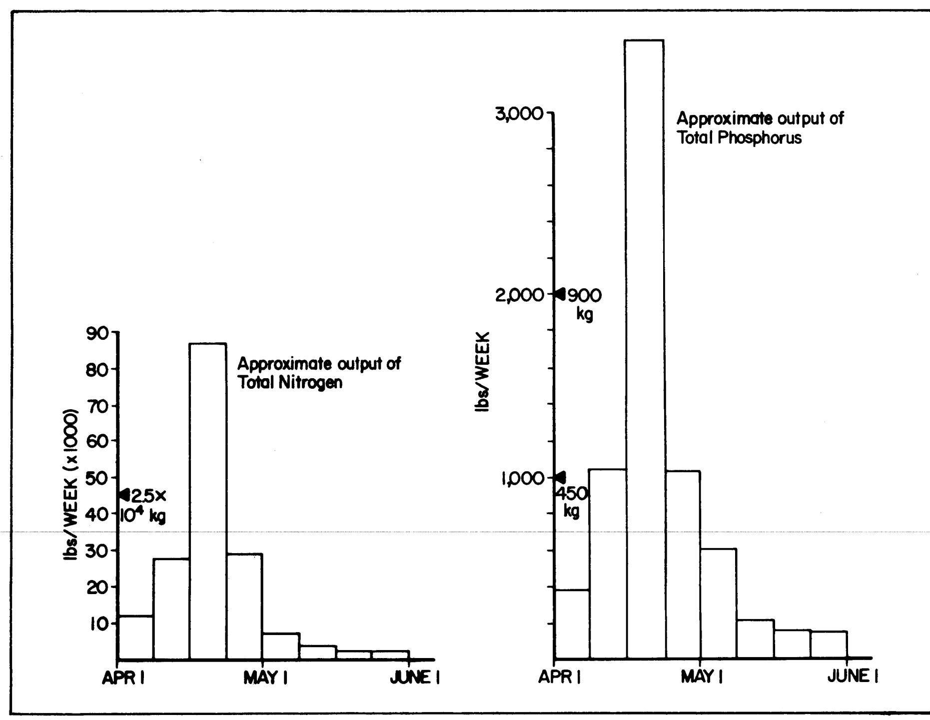
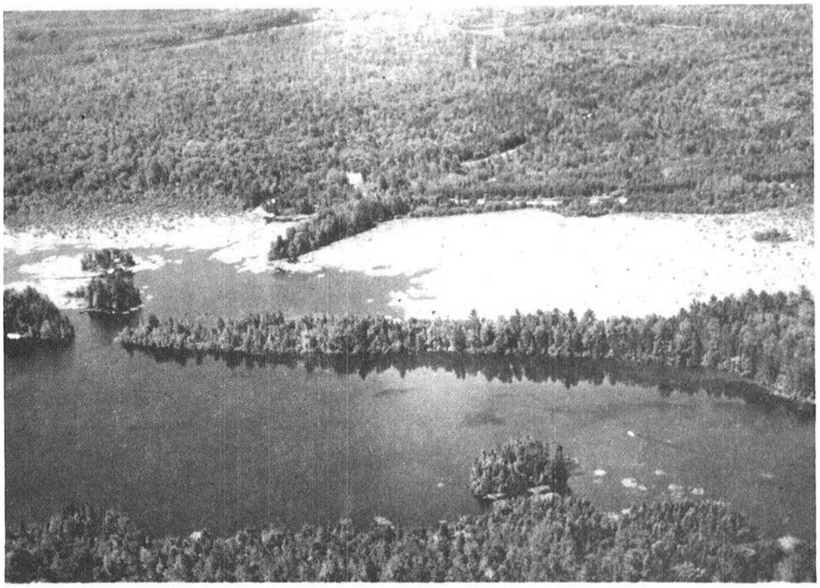
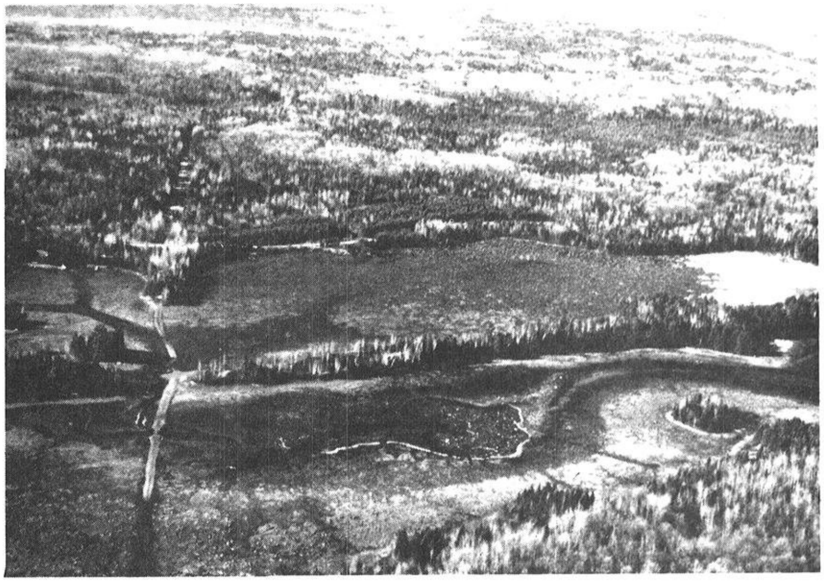


FIGURE 19. *Nitrogen and phosphorus output, Mondeaux Flowage, spring, 1972.*

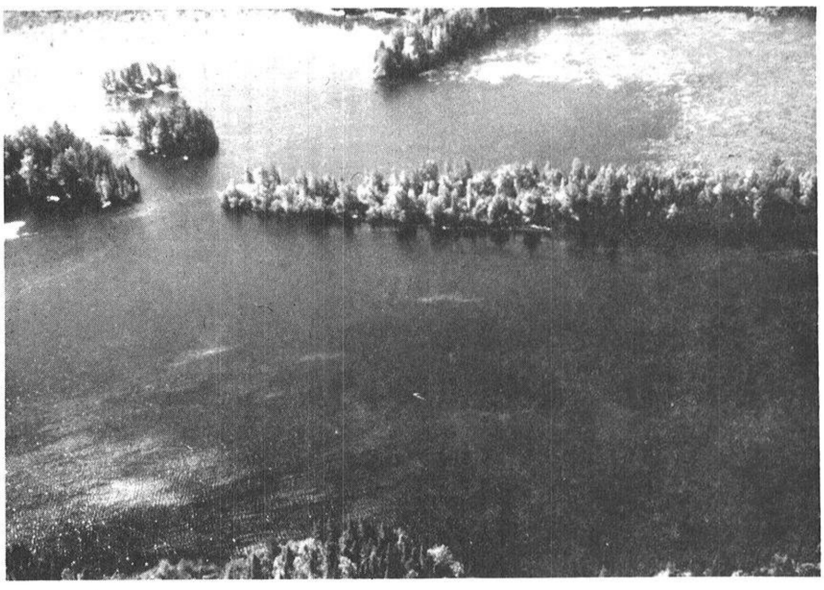
FIGURE 20. *Aerial photo comparison before-during-after drawdown, Mondeaux Flowage: (Compliments of Earl Gingles)*



(a) August, 1971;



(b) November, 1971;



(c) August, 1972.

LITERATURE CITED

Bagnall, L. O.
1970. Processing, chemical composition and nutritive value of aquatic weeds as affecting the economics of their removal and utilization. Eng. Rep. No. 2, Agric. Eng. Dep. Univ. Fla., Gainesville. 12 p.

Bartch, A. F.
1954. Practical methods for control of algae and water weeds. U. S. Public Health Service. Public Health Rep. 69:749-757.

Beard, T. D.
1969. Impact of an overwinter drawdown on the aquatic vegetation in Murphy Flowage, Wisconsin. Res. Rep. No. 43. Dep. Nat. Resour., Madison, Wis., 16 p.
1973. Overwinter drawdown. Impact on the aquatic vegetation in Murphy Flowage, Wisconsin. Dep. Nat. Resour. Tech. Bull. No. 61, Madison, Wis. 14 p.

Björk, S.
1972. Bringing sick lakes back to health. Teknisk Tidskrift 11:111-118.

Bonnema, K. and W. Johnson.
1971. Control of aquatic vegetation, algae, leeches and swimmers itch in 1971. Minn. Dep. Nat. Resour. 8p. mimeo.

Born, S. M.
1972. Inland Lake Demonstration Project Progress Report, 1968-1972. Inland Lake Demonstr. Proj., Madison, Wis. (Upper Great Lakes Reg. Comm.), 15 p.

Born, S. M., T. L. Wirth, E. Brick and J. O. Peterson
1973. Restoring the recreational potential of small impoundments: the Marion Millpond experience. Wis. Dep. Nat. Resour. Tech. Bull. No. 71, Madison, Wis. 20 p.

Bruhn, H. D. and D. F. Livermore
1970. Physical properties and processing characteristics of macrophytes as related to mechanical harvesting. Preprint pap. No. 70-582. Annu. Meet. Am. Soc. Agric. Eng. St. Joseph, Mich. 17 p.

Buglewicz, E. G.
1972. The impact of reduced light penetration on a eutrophic farm pond. M.S. Thesis Univ. Nebr.

Carranza, C. and J. Walsh
1972. A study of nutrient sources pertaining to the duckweed problem in Rubberthread Pond, in Easthampton, Massachusetts. Rep. by Baystate Environ. Consultants. Springfield, Mass. 66 p.

Chapman, W. H., H. L. Fisher and M. W. Pratt
1968. Concentration factors of chemical elements in edible aquatic organisms. Lawrence Radiat. Lab., Univ. Calif., Livermore. 50 p.

Cottam, G. and S. Nichols
1970. Changes in water environment resulting from aquatic plant control. Tech. Rep. OWRR B-019-Wis. Univ. Wis. Water Resour. Cent., Madison, Wis. 27 p.

Crowell, T. E., J. H. Steenis and J. L. Sincock
1967. Recent observations of Eurasian water milfoil in Currituck Sound, North Carolina and other coastal Southeastern states. Mimeogr. 8 p.

Curtis, J. T.
1959. The Vegetation of Wisconsin. The Univ. Wis. Press, Madison. 657 p.

Dore. W. G.
1969. Wild-rice. Can. Dep. Agric. Publ. No. 1393, Queens printer, Ottawa, 84 p.

Dunst, R. et al.
1974. Survey of lake rehabilitation techniques and experiences. Dep. Nat. Resour. Tech. Bull., No. 75, 180 p.

Eicher, G.
1947. Aniline dye in aquatic weed control. J. Wild. Manage. 11(3):193-197.

Fitzgerald, G.
1968. Detection of limiting or surplus nitrogen in algae and aquatic weeds. J. Phycol. 4:121-126.
1969a. Field and laboratory evaluation of bioassays for nitrogen and phosphorous with algae and aquatic weeds. Limnol. Oceanogr. 14:206-212.
1969b. Some factors in the competition of antagonism among bacteria, algae and aquatic weeds. J. Phycol. 5:351-359.

Gerloff, G. C.
1969. Evaluating nutrient supplies for the growth of aquatic plants in natural waters. *In:* Eutrophication: causes, consequences, correctives. Nat. Acad. Sci., Washington D.C. p. 537-555.

Gerloff, G. and P. H. Krombholz
1966. Tissue analysis and nutrient availability for the growth of angiosperms aquatic plants. Limnol. Oceongr. 11:529-537.

Goulder, R.
1969. Interactions between the rate of production of freshwater macrophytes and phytoplankton in a pond. Oikos 20:300-309.

Great Britain
1959. Water conservation and weed control. World Crops 11:375.

Hall, T. F., W. T. Penfound and A. D. Hess
1946. Water level relationships of plants in the Tennessee Valley with particular reference to malaria control. J. Tenn. Acad. Sci. 21:18-59.

Harlan, J. R. and J. de Wet
1965. Some thoughts about weeds. Econ. Bot. 19:16-24.

Hasler, A. D. and E. Jones
1949. Demonstration of the antagonistic action of large aquatic plants on algae and rotifers. Ecology 30:359-364.

Hutchinson, G. E.
1970. The chemical ecology of three species of *Myriophyllum.* Limnol. Oceanog. 15:1-5.

Jewell, W. J.
1971. Aquatic weed decay. J. Water Pollut. Control Fed. 43:1457-1467.

Karl, G.
1972. Summary list of herbicides and algicides. Wis. Dep. Nat. Resour., Madison. Mimeogr. 5 p.

Klessig, L. and D. Yanggen
1972. Wisconsin lakeshore property owners associations. Inland Lake Renewal and Shoreline Manage. Demonstr. Proj. Rep. Madison, Wis. 72 p.

Klingbiel, J., L. Stricker and O. Rongstad
1968. Wisconsin farm fish ponds. Univ. Wis. Ext. Man. No. 2, Madison, Wis. 45 p.

Koegel, R. G., H. D. Bruhn and D. F. Livermore
1972. Improving surface water conditions through control and disposal of aquatic vegetation. Univ. Wis. Water Resour. Cent. Rep. OWRR-B-018-Wis. Madison. 46 p.

Lange, S. R.
1965. The control of aquatic plants by commercial harvesting, processing and marketing. South. Weed Conf. Proc. 18:536-542.

Lantz, K. E., J. T. Davis. J. S. Hughes and H. E. Schafer
1964. Water level fluctuation—its effects on vegetation control and fish population management. Proc. 18th annu. conf. Southeast Assoc. Game and Fish Comm. 18:483-494.

Lee, G. F.
1970. Eutrophication. Occasional Pap. No. 2, The Univ. Wis. Water Resour. Cent., Madison. 39 p.

Lee, G. F., E. Bentley and R. Amundson
1970. Effect of marshes on water quality. Mimeogr., Water Chem. Program, Univ. Wis., Madison, 25 p.

Little, E. C. S.
1968 a. Handbook of utilization of aquatic plants. Food and Agric. Organ. of the United Nations. Rome. 123 p.
1968 b. The control of water weeds. Weed Res. 8(2):79-105.

Livermore, D. F. and W. E. Wunderlich
1969. Mechanical removal of organic pro-

TECHNICAL BULLETINS (1972-1974)*

No. 52 Mercury levels in Wisconsin fish and wildlife (1972) Stanton J. Kleinert and Paul E. Degurse

No. 53 Chemical analyses of selected public drinking water supplies (including trace metals). (1972) Robert Baumeister

No. 54 Aquatic insects of the Pine-Popple River, Wisconsin. (1972) William L. Hilsenhoff, Jerry L. Longridge, Richard P. Narf, Kenneth J. Tennessen and Craig P. Walton

No. 56 A Ten-Year Study of Native Northern Pike in Bucks Lake, Wisconsin Including Evaluation of an 18.0-inch Size Limit. (1972) Howard E. Snow and Thomas D. Beard

No. 57 Biology and Control of Selected Aquatic Nuisances in Recreational Waters. (1972) Lloyd A. Lueschow

No. 58 Nitrate and Nitrite Variation in Ground Water. (1972) Koby T. Crabtree

No. 59 Small Area Population Projections for Wisconsin. (1972) Douglas B. King, David G. Nichols and Richard J. Timm

No. 60 A Profile of Wisconsin Hunters. (1972) Lowell L. Klessig and James B. Hale

No. 61 Overwinter Drawdown: Impact on the Aquatic Vegetation in Murphy Flowage, Wisconsin. (1973) Thomas D. Beard

No. 62 Eutrophication Control: Nutrient Inactivation by Chemical Precipitation at Horseshoe Lake, Wisconsin. (1973) James O. Peterson, J. Peter Wall, Thomas L. Wirth and Stephen M. Born

No. 63 Drain Oil Disposal in Wisconsin. (1973) Ronald O. Ostrander and Stanton J. Kleinert

No. 64 The Prairie Chicken in Wisconsin. (1973) Frederick and Frances Hamerstrom

No. 65 Production, food and harvest of trout in Nebish Lake, Wisconsin. (1973) Oscar M. Brynildson and James J. Kempinger

No. 66 Dilutional pumping at Snake Lake, Wisconsin—a potential renewal technique for small eutrophic lakes. (1973) Stephen M. Born, Thomas L. Wirth, James O. Peterson, J. Peter Wall and David A. Stephenson

No. 67 Lake sturgeon management on the Menominee River. (1973) Gordon R. Priegel

No. 68 Breeding duck populations and habitat in Wisconsin. (1973) James R. March, Gerald F. Martz and Richard A. Hunt

No. 69 An experimental introduction of coho salmon into a landlocked lake in northern Wisconsin. (1973) Eddie L. Avery

No. 70 Gray partridge ecology in southeast-central Wisconsin. (1973) John M. Gates

No. 71 Restoring the recreational potential of small impoundments: the Marion Millpond experience. (1973) Stephen M. Born, Thomas L. Wirth, Edmund O. Brick and James O. Peterson

No. 72 Mortality of radio-tagged pheasants on the Waterloo Wildlife Area. (1973) Robert T. Dumke and Charles M. Pils

No. 73 Electrofishing boats: Improved designs and operating guidelines to increase the effectiveness of boom shockers. (1973) Donald W. Novotny and Gordon R. Priegel

No. 74 Surveys of toxic metals in Wisconsin. (1974) John G. Konrad et al.

No. 75 Survey of Lake Rehabilitation Techniques and Experiences. (1974) Russel Dunst et al.

No. 76 Seasonal movement, winter habitat use, and population distribution of an east central Wisconsin pheasant population. (1974) John M. Gates and James B. Hale

* List of all technical bulletins in the series available from the Department of Natural Resources, Box 450, Madison, Wisconsin.

ACKNOWLEDGEMENTS

The author wishes to acknowledge, for obtaining papers used to review techniques, R. Dunst, Department of Natural Resources (DNR); and for data gathered on the Mondeaux Flowage, G. Bevers and E. Gingles, DNR, and V. Hancock, U.S. Forest Service.

For reviewing the manuscript and providing valuable information, D. Livermore, J. Peterson, and S. Born, University of Wisconsin; and C. Bryant, Aquamarine Corp.

For critically reviewing parts of the manuscript, T. Wirth, T. Beard, D. Winter and D. Knauer, DNR; W. Mann, U.S. Forest Service; K. Maleug, Environmental Protection Agency; P. Uttormark, R. Koegel and H. Bruhn, University of Wisconsin; and R. White, Michigan State University.

The manufacturers of harvesting equipment, University of Wisconsin Extension and Wisconsin Department of Natural Resources personnel, Lakeshore Property Owners' Associations, sanitary districts and many others provided information for this report.

This study was conducted in cooperation with the Wisconsin Department of Natural Resources and the University of Wisconsin Extension as part of the Inland Lake Renewal and Management Demonstration Project. Funding for the project was provided by the Upper Great Lakes Regional Commission.

The author is Aquatic Biologist, Environmental Resources Unit, University of Wisconsin Extension.

Edited by Ruth L. Hine.