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Extensive infestations of obnoxious aquatic weeds cause problems in the operation and maintenance of irrigation, flood control, navigation and water supply systems, including a reduction in carrying capacity by retardance of flow from submersed aquatic plants, increased waterloss from the transpiration of emersed and marginal aquatic plants, the clogging and deterioration of structures in the distribution system from floating aquatic plants, and the limiting of operational control by terrestrial ditchbank vegetation. Because these problems usually become more serious with advance of season, it is important that preventive measures of control be applied at the appropriate time, and that full consideration be given to environmental aspects of the problem. The purpose of this paper is to discuss the environmental impact of aquatic plant control operations.

AQUATIC PLANT CONTROL AND ENVIRONMENTAL CONSEQUENCES

INTRODUCTION

Extensive infestations of obnoxious aquatic weeds cause problems in the operation and maintenance of irrigation, flood control, navigation and water supply systems, including a reduction in carrying capacity by retardance of flow from submersed aquatic plants, increased waterloss from the transpiration of emersed and marginal aquatic plants, the clogging and deterioration of structures in the distribution system from floating aquatic plants, and the limiting of operational control by terrestrial ditchbank vegetation. Because these problems usually become more serious with advance of season, it is important that preventive measures of control be applied at the appropriate time, and that full consideration be given to environmental aspects of the problem. The purpose of this paper is to discuss the environmental impact of aquatic plant control operations.

CONTROL OF SUBMERGED PLANTS

Submerged plants complete their entire life cycle, exclusive of flowering and pollination under water. Waterweed is typical submerged plants that grow in dense stands or mats. Other troublesome submerged species that grow densely include pondweed, bushy pondweed, watermilfoil, coontail, fanwort, and bladderwort.

Chemicals for controlling submerged weeds can be applied in various ways. Granules man be spread from a boat, from the shore, or by aircraft. Care must be taken to obtain uniform coverage. Granules are especially useful for spot treatments near boat landings or swimming areas. Liquid herbicides may be sprayed or pumped into the water. Again, boats, aircraft, or even hand pumping from the shoreline may be used. As a rule, the more evenly the chemical is distributed, the better the results will be. Spot treatment of problem areas with liquids in very large areas may be desirable. Usually more material per acre-foot of water is needed when making spot treatments than when making overall treatment, because the nontreated adjacent water will have a diluting effect. Where dense weeds cover an entire pond, only one-third of the pond should be treated at a time to prevent oxygen depletion due to decaying plant growth. When treating 1/3 of the pond, applications should be made at weekly intervals until the entire ponds is treated. (1,13,14,15,16,17).

CONTROL OF EMERGENT PLANTS

Emergent plants may grow in moist or swampy shoreline soils and extend into water three feet or more in depth. Many emergents are valuable duck foods, and should not be eliminated if waterfowl are wanted. Principal types include species of rushes, bulrushes, cattails, reeds, sedges, and arrowheads.

Foliar sprays should be applied in early summer as the leaves are approaching full size, but before flowering. If water is used as the diluent or carrier, a small amount of detergent or other wetting agent will improve coverage of the plant surfaces. The plant foliage should be completely wetted. Applications should be made during mid-day periods when the foliage above water is free from dew or rain.

Granular formulations act more slowly than liquids, but they may give more long-lasting results. If attaclay or a similar carrier is used, the herbicide may be spread with a cyclone seeder or by hand. The granules settle to the bottom and release the chemical that will be absorbed through the plant roots. As with foliar sprays, granular applications are made in late summer or fall, however, the effects may not be noticed until the following spring when the treated plants fail to develop. If granules are spread on choppy water, distribution will be uneven, and results may be unsatisfactory.

In making spray applications for controlling emergent weeds, there are two basic methods of calculating the dosage and application rate: (1) quantity of herbicide per surface area treated, and (2) quantity of herbicide per volume of spray solution.

For treating areas of one acre or more, the first method should be used. The important consideration with this method is the amount of herbicide applied per acre. The amount of carrier will vary with the spray equipment, nozzle sizes, and pressure. For treating areas of less than one acre, it is more practical to use the herbicide-per volume method and to spray foliage to the run-off point or until thoroughly wetted. With most herbicides, the container label will give directions for applications by both methods. (1,13,14,15,16,17).

CONTROL OF FLOATING PLANTS

The most common floating plants are duckweed, water lily, spatterdock, and watershield. The water lily types are valued by fisherman as long as ample room is left for fishing, but in areas used for boating, swimming, or water skiing, water lilies are serious nuisances and must be kept under control.

Plants and the water surface should be treated by spraying, taking care to obtain even distribution in the area of plant growth. If water is colder than 60 F., or if plants are not growing actively, the area should not be sprayed. For floating plants that are rooted on the bottom, granular formulations may be used. (1,13,14,15,16,17).

CONTROL OF ALGAE

Most serious problems with algae are usually associataed with domestic water supply reservoirs or small farm ponds.

Control is most effective and least costly when undertaken before the algae become dense enough to constitute a problem. Some reservoir managers make a daily microscopic examination of the water to determine when treatment should be scheduled. Through experience with a given body of water, one may be able to anticipate when chemicals should be applied.

The amount of chemical per treatment and the number of required treatment varies with the hardness of the water. In soft water, one treatment may suffice. In hard water, however, three or four treatments may be needed throughout the summer because the regrowth of algae can be quite rapid in such water. If results are not evident within seven days after treatment, another application may be made.

Trout are very sensitive to some chemicals, especially copper sulfate, and cannot tolerate levels required for control of certain species of algae. (1,13,14,15,16,17).

METHODS OF APPLICATION

The applicator should consider only those herbicide formulations specifically registered and labeled for aquatic weed control.

The 3- to 5-gallon pressure-type sprayers available at most home garden centers and hardware and farm supply stores are adequate for treating small ponds. Ponds of 5 acres or more may be more efficiently treated with heavier, commercial-type spray equipment.

Granules can be spread by hand in small areas such as boat landings and swimming sites. Hand-operated, crank-type fertilizer and seed spreaders will do a satisfactory job in larger areas. Large versions of these spreaders are used for large-scale commercial granule applications. They operate on the principle of the cinder spreaders used on highways, and are capable of dispersing granules in 30- to 35 foot swaths. These units are often powered by a 12-volt D.C. motor that operates from an auto battery. Helicopters and airplanes have been used effectively to apply chemicals, particularly granules, in large-scale operations.

Chemicals, especially 2,4-D and silvex sprays, should be applied on a calm day when dangers from drifting can be avoided. With such precautions, damage to desirable vegetation is minimal, and operators are protected from excessive contact and inhalation of spray.

Chemical spillage, especially around stock pond areas or where pets and children may be exposed, must be cleaned up. Herbicides should never be stored where children can reach them. Labels should be studied and their instructions for safe and proper use observed.

Herbicide application can start at the margins of the lake or pond and progress toward the deep water. Fish and other organisms will tend to move ahead of the herbicide-treated water into the deeper areas where toxic concentrations can be avoided.

Lakes and ponds that have a high rate of inflow should be lowered prior to treatment so as to insure adequate contact time for the herbicide. The spillway should be closed and the treated water retained for at least 3 days before overflow. The amount of drawdown will vary according to the situation. Care must be taken to avoid excessive exposure of bottom areas.

After the application is completed, the spray equipment should be flushed with large quantities of water.

Waters should be treated for aquatic weeds in late spring or early summer when plants are young and actively growing. Treatment at this time of year usually gives optimal control with a minimum of chemical. Applications in late summer or early fall require more chemical and usually give a slower, erratic control. Furthermore, access to normally dense aquatic vegetation is best in the spring or early summer before the plants reach the surface.

1. Be certain of the identity of the vegetation to be treated and the capability of the chemical to control it.
2. Obtain a permit to treat any lake or pond, whether for weed control, cleaning, or other purposes.
3. Never use more chemical than suggested on the label. Fish and other valuable aquatic life may be killed.
4. Use treated water only as suggested on the label. (1,3,13,14,15,16,17).

ENVIRONMENTAL CHANGES CAUSED BY AQUATIC PLANT CONTROL

The sudden elimination of a dense growth of vegetation from an aquatic environment very often causes side effects that can produce significant changes in the biological and physical makeup of a lake, pond, or stream.

Following the death of larger weed plants in a pond or lake, a greenish or yellowish-brown turbid condition may be noticed. This condition is due to the presence of billions of microscopic algal cells which have utilized the nutrient for growth and reproduction. The blue-green algae are often responsible for a pea green appearance, whereas other algae and various one-celled organisms cause the yellowish-brown colors in water. When conditions are optimal for development of algae, a dense bloom can develop quickly. These dense blooms of plankton algae cut down light penetration and thereby inhibit the reestablishment of those species killed in treatment, but the algae may turn out to be more objectionable than the original weed infestation.

Some aquatic vegetation is necessary for the reproduction and survival of certain fish (pickerel, golden shiners, and others). It follows that where desirable fish are dependent on aquatic vegetation, portions of water should be left untreated.

Aquatic plants provide habitat in lakes and ponds for waterfowl and fish, but may be in conflict with certain types of water use.

Aquatic plants add essential oxygen to the water, but under some conditions, their respiration and decomposition may reduce the oxygen to dangerously low levels for fish survival.

Aquatic plants play an important role in food chains; however, too many plants may contribute to overcrowded and poor quality fish populations.

There is no easy cure-all for controlling undesirable aquatic vegetation. Dredging to deepen shallow edges may help, but may also create hazards and fish management problems.

Aquatic plant control with chemicals can be successful and very satisfactory. Once a weed problem is under control, diligent treatment of regrowth is necessary to maintain control. It is much easier and less expensive to conduct periodic maintenance or to make spot treatments than it is to wait until treatment of the entire area is necessary. (1,3,13,14,15,16,17).

WORKSHOP ON AQUATIC WEEDS1/

The purpose of this "Workshop" is to bring together experts in the field of aquatic weed control for informal discussion of current problems and of how the U.S. Environmental Protection Agency can assist in their solution. It was recognized that the U.S. Army Corps of Engineers, the U.S. Department of Agriculture, and the U.S. Department of the Interior have programs in aquatic weed control. However, there are some areas of research that are of interest to all of these Federal agencies, and cooperation, expressed as joint funding of certain projects, should be encouraged on a national basis.

Aquatic weeds are threats to many areas of the country. Two species are of special importance, hydrilla (**Hydrilla**

1/Abstracted and updated from the proceedings of a workshop held at the Enviromental Protection Agency, Environmental Research Laboratory, Gulf Breeze, Florida, February 25-26, 1980.

verticillata) in the southern United States, and eurasian watermilfoil (**Myriophyllum spicatum**) in the northern United States, but pondweeds (**Potamogeton** spp.) and filamentous bluegreen algae are also widespread pests. Brazilian elodea (**Egeria braziliensis**) is also a problem in some locations. Although effective herbicides are available, it is often difficult to control hydrilla, watermilfoil, pondweed, and brazilian elodea with herbicides or plant growth inhibitors, not only because they are submersed and therefore hard to reach with conventional methods of chemical treatment, but also because public perception of possible adverse effects precludes herbicidal treatment.

Filamentous algae may be controlled with substances that contain copper, but this metal may be a pollutant in some situations.

At present, chemical means of control, in general, are the simplest and least expensive methods of aquatic weed control. They do, however, sometimes have undesirable effects, such as lack of target plant specificity, toxicity to animals, and persistence of residues.

For these reasons, it would be best for EPA to concentrate its research efforts on development and testing of biological, mechanical and integrated controls. Emphasis should be placed on biological and integrated (chemical, biological, mechanical) methods. Chemical control should be addressed as part of an integrated scheme, with a view toward use of less chemicals for weed control. In either case, immediate results should not be expected because a large amount of methods development is needed in the biological area, and some methods are not developed to the point that they can be meshed with others in integrated programs. Also, because of differences in weed species and in water bodies, methods must be adapted to local conditions.

CHEMICAL CONTROL

Aquatic plants may be killed, controlled, and maintained at acceptable population densities by herbicides and plant growth inhibitors. Management of aquatic plant biomass by synthetic chemicals is, in general, the easiest and least expensive method available, but it may have undesirable effects, such as lack of target plant specificity, toxicity to animals, and persistence of residues. Steward (12) listed chemicals used for control of aquatic weeds:

Floating weeds: amitrol T, diquat, silvex, 2,4-D;
Immersed broadleaf weeds: amitrol, amitrol T, silvex, 2,4-D, dalapon;
Submersed weeds and algae: organic copper, copper sulfate, copper carbonate, diquat, silvex, 2,4-D, dichlobenil, fenac, simizine, endothall;
Irrigation and drainage ditch banks. Amitrol T, 2,4-D, dalapon, dicamba, dinoseb, diuron, hexazinone, krenite, and TCA;

Irrigation and drainage canals: copper, diquat, duiron, endothall, acrolein, aromatic solvent.

The methods by which these chemicals are applied to weeds are important with regard to extent of control and effects upon non-target species. Herbicides and growth regulaters are often formulated with organic polymers to control drift, on granules of various compositions, in oil droplets, or with synthetic plastics, elastomers, waxes, or naturally-ocurring polymers that all slow or control release of the chemicals. (5).

Herbicides and plant growth regulators are relatively non-persistent in natural environments. They cause changes in aquatic ecosystems, however, and their impacts must be judged in relation to (1) toxicity to the target species, (2) relative toxicity to non-target species, (3) fate of residues and their significance to water, fishes, crops, livestock, and foods, (4) conditions that affect toxicity, efficacy, and persistence, and (5) synergizing or antagonizing activity of carriers, formulations, metabolites, degradation products, or other pesticides. (3).

The consensus of the meeting was that, in spite of problems associated with the five points listed above, chemical control, when used correctly, is environmentally safe and should be continued in the future. Most discussion was devoted to experience of the discussants with regard to efficacy and correct usage--correct usage as it relates to goals of control and maintenance programs--development of new herbicides and formulations, and use of chemicals in different types of water and geographical areas.

Chemical control is the dominant method used for aquatic weeds today. We should discuss this method from the standpoints of effectiveness, environmental effects, and environmental compatibility of current compounds, and can consider newer controlled-release methods, growth regulators, abcissic acid, allelopathic compounds, and natural growth regulators. We should consider mainly the three plant species that are controlled by chemicals, i.e., hydrilla, eurasian watermilfoil, and waterhyacinth. Also, filamentous algae must be considered because chemicals are used to control them in western irrigation systems.

AQUATIC WEED CONTROL PROBLEMS

~~1~~. **Inventory of weed problems.** A nationwide inventory of aquatic weed problems is needed. Although this is not specifically a chemical control problem, it is very important to control programs: chemical companies need to know the extent of weed problems in order to plan trial and development research; control personnel need to know the distribution of aquatic weed species. The inventory should relate to user group perceptions, which are very important with regard to weed control. For example, irrigation managers desire weed-free water whereas fishermen may want a two-meter margin of plants around the lake.

~~2~~. **Lack of basic data on aquatic weeds.** Relatively little is known about the basic biology of aquatic weeds. It is not known why a species may be a pest in one lake, but in reasonable biomass in a nearby lake. Hydrilla may be a pest in a lake for one year, but not in the following year, after which, it may become a pest again. A species may attain high biomass in one portion of a lake, but not another. If we knew why these phenomena occur, safe methods for control might be devised. Herbicides used for control of aquatic plants are not developed in relation to any physiological characteristics of those plants. In fact, they are usually herbicides that were developed for use on terrestrial plants and later found to be effective against aquatic weeds. We are trying to control target species without knowing their characteristics or how they differ from non-target species. Research is needed on the basic biology of major aquatic weed species.

~~3~~. **Maintenance level for aquatic weeds.** In many areas of Florida, waterhyacinth is no longer a problem because of effective maintenance programs. Acceptable maintenance levels should be achieved for other plants. This is, however, especially difficult for submersed plants, and different treatment will be required for different water bodies in relation to weed species and individual characteristics of those bodies. Just as important is the level of control as related to effects on the whole system and what degree of control is acceptable in relation to use.

4. **Effectiveness of 2,4-D for maintenance control of waterhyacinth in Florida.** After lengthy discussion, it was agreed that 2,4-D is an effective and evnironmentally safe chemical for control of waterhyacinth and that insects and pathogens probably aid in control. Diquat is now being used in South Florida, and the general consensus was that it is not as efficient or environmentally safe as 2,4-D. Diquat kills many non-target plants, such as bullrushes, but because the public perceives 2,4-D as a dangerous chemical, although it is not, diquat is used instead. Public perception of effects of chemical spraying is not always correct and should not be the guiding principle for weed control by chemicals.

5. **Controlled release formulations.** New formulations of herbicides, particularly controlled release formulations that allow low concentrations of herbicides to be effective, have been developed. These are particularly effective in preventing regrowth after application to hydrosoil when it is exposed to air during drawdowns or periods of low flow. It is estimated that these formulations will be effective for at least a complete growing season or a full year. As yet, there are not enough data to determine effects of long-term exposure of non-target organisms to the lowest concentration of 2,4-D that inhibits growth. Also, research is needed on effects of water chemistry and water temperature on persistence and effectiveness of herbicides used in controlled release formulations.

Recommendations

1. Develop methods that use conventional herbicides to reduce plant biomass, with subsequent maintenance by controlled release herbicides to prevent regrowth.

2. Develop research methods for determination of dissipation, metabolism, and physical breakdown of chemicals in static and flowing water sites. The latter use-pattern is of primary importance to aquatic vegetation control and management in western states where irrigation systems are severely disrupted by aquatic weeds. The goal of this research is to help establish the appropriate application and water management techniques that will minimize or eliminate exposure of man, livestock, and non-target aquatic plants and fishes to toxic chemicals.

3. Determine herbicide concentrations in target aquatic plants as a means of addressing potential impact of ingestion of target vegetation by non-target vertebrate and invertebrate grazers. This is a neglected area of research that may have benefits beyond the evaluation of non-target species impact: information on efficiency of herbicide uptake and retention in target plants may point to more selective application techniques via placement and formulations of herbicides.

4. Determine the retention of trace amounts of aquatic herbicides in representative crops normally grown in areas where irrigation is dependent upon conveyance systems in which aquatic

herbicides may be used. This information is essential for evaluation of impacts on crops and is a prerequisite for establishment of commodity tolerances by EPA.

5. Determine the significance of nutrient release from decomposing target aquatic plants. Under what conditions might one expect that algal blooms resulting from nutrient release may be more detrimental than existing macrophyte populations?

6. Determine the long-term effects of controlled release formulations. These are likely to be chronic, sub-lethal concentrations that may affect microflora, benthos, and infauna. What potential is there for direct ingestion of controlled release formulation pellets?

7. Determine the potential hazard of water-borne, herbicide-laden silt and detritus.

8. Support research on potential use of naturally-occurring substances that have herbicidal qualities. These may be present on soil or water or may be extracted from species that use extracellular toxic substances to survive competition with other species. Determine specificity, persistence, and toxicity of allelopathogens and other natural substances.

BIOLOGICAL CONTROL

Structure and dynamics in natural communities are regulated by complex biological phenomena, one of which is the effect of a predatory species on population density of a prey species. An important part of such population density control is the dampening of plant biomass by herbivores (e.g. biomass of phytoplankton as a function of grazing rates by herbivorous zooplankton, (11). Overproduction by primary producers in a system is compensated for through consumption by herbivores, whose numbers and biomass are controlled, at least in part, by prey numbers and biomass. The result of such a cybernetic system is maintenance of constancy of biomass for a period of time. (9).

Biological weed control by man attempts to use natural predators to control biomass of weed species. From theory expressed in the previous paragraph, it is clear that a reproducing population of plant predators will not eradicate weeds, but that numbers of prey and predator will oscillate (6), both existing at concentrations acceptable to man.

So far, application of biological controls to weed problems has met with moderate success. For example, the alligatorweed flea beetle (**Agasicles hygrophila**) has controlled alligatorweed (**Alternathera philoxeroides**) well in Louisiana, but not in Alabama (17). A large amount of work is continuing of fishes (4), insects, and plant pathogens (2,3), but biological control remains only a potential tool for large-scale control of aquatic weeds.

Researchers in biological control of aquatic plants have a tremendous responsibility to environmental protection because of the complexity of aquatic ecosystems. Any intentional alteration of these systems involves the risk of undesirable consequences. The risk is compounded when the modification is irreversible, as is typically the case in introduction of non-native species that subsequently reproduce. Nevertheless, potential benefits from introduction of plant borers and pathogens for control of nuisance aquatic plants can outweigh the risks if strict guidelines are followed. Suggested guidelines include (1) the need for an introduction must be clearly established, (2) the organism must have a desirable ecological and economic impact, (3) the species must have minimal niche overlap with native species, (4) it should cause minimal reduction of nontarget species, and (5) field releases should be studied and ecological impact determined. Disease interrelationships should be carefully examined, and methods for control of the introduced species should be established prior to large scale introduction.

BIOLOGICAL METHODS

Use of Insects

~~1.~~ **Host specificity.** There is a large gap in our knowledge of host specificity with regard to insects and aquatic plants. One researcher felt intuitively that aquatic insects often do not attack specific host species as do terrestrial insects, but tend to attack certain types of plants or species groups. It would be difficult, if not impossible, to test an insect against all plants that may be exposed to it. Also, an insect may feed on many plant species in the laboratory, yet be found on only one or two species in the field.

~~2.~~ **Cost.** The cost of introducing insects is very high: finding suitable species, quarantine, and testing can take 8 - 10 years at a cost of several million dollars.

~~3.~~ **Potential for altering ecosystems.** A very important question is relative to the potential an insect has for altering an aquatic ecosystem. Besides killing the weeds, an insect could alter an ecosystem in an acceptable way if it did not affect a favored plant species, thus making moot the problem of host specificity. As a point in proof that host specificity is not necessary, it was mentioned that fishes often do not feed selectively, yet there is no requirement for specific food selection by them.

Use of Plant Pathogens

~~1.~~ **Lack of information on aquatic plant pathogens.** Most work on plant pathogens, such as fungi, has been done on terrestrial species. Little is known with regard to methods for isolation, maintenance, and testing of aquatic pathogens. Aquatic pathogens are very specialized: they are often obligate parasites that cannot now be cultured. We need to learn how to culture them and how to expose submersed weeds to them. Many pathogen species occur in soil and water attacking plants in both systems. We do not know if it is safe to use them for aquatic weed control.

—Genetic manipulation may be an important tool in development of plant pathogens. However, most mutations result in loss of pathogenicity, rather that enhanced pathogenicity.

~~2.~~ **Cost of producing pathogens.** Once a pathogen is isolated and proven to be useful for weed control, cost of mass culturing and production on inocula will be relatively inexpensive, except for obligate parasites.

~~3.~~ **Necessity of repeated treatments with pathogens.** Since numbers of pathogenic organisms will decline as plant numbers decline, it may be necessary periodically to reinstigate epidemics.

Use of Fishes

~~1.~~ **Grass carp.** The major comments with regard to use of the grass carp (**Ctenopharyngodon idella**) were reservations on its ability to control vegetation and on possible adverse environmental effects. Although grass carp have controlled weeds in some areas, they have not done so in others. They are also known to have caused changes in water quality; some people fear that the carp may reduce stocks of sport fishes, such as bass and bluegill; and control, when it occurs, is slow compared to chemical and biological methods. However, once it occurs, is slow compared to chemical and biological methods. However, once control is established with fishes, it lasts for a relatively long period of time.

2. **Hybrid carp.** The hybrid carp, a cross between the female grass carp (**C. idella**) and the male bighead carp (**Hypophthalmichthyes nobilis**), has been proposed for introduction for weed control. It is now being tested in several laboratories and field situations. One researcher said it has "the greatest potential as an environmentally acceptable plant control method that I have ever encountered." An important advantage of the hybrid over the grass carp is that the hybrid consumes both plants and filamentous algae, whereas the grass carp eats only plants.

Testing of hybrid carp for weed control has begun recently in the United States, and its use, singly and in combination with other control methods, needs to be investigated.

Recommendations

1. Comparative studies should be made between lakes where a weed species is a problem and lakes where it is not a problem. For example, in Lake Jackson (Florida), hydrilla seems to be under natural controls. The reasons for such control in this and other lakes may or may not be biological, but they should be studied.

2. The search for aquatic plant pathogens should continue. Methods for isolation and maintenance of pathogens should be developed. A battery of pathogen types should be developed for use on each weed species that has resistant strains. Endemic species of pathogens should be used whenever possible.

3. Research should be done on the relation of environmental stresses to susceptibility of host plants to pathogens.

4. EPA should fund research in technology development for production of hybrid carp.

5. The basic biology of the hybrid carp should be studied, i.e., food preference of age classes, growth rates, etc. in the field and laboratory.

6. Effects of hybrid carp on total ecosystems should be studied.

MECHANICAL CONTROL AND HABITAT MANIPULATION

Mechanical control of aquatic weeds involves collection of plants with subsequent treatment and return to the water, or removal from the infested water body (harvest method). The former may be appropriate for eutrophic systems, but the harvest method is used most often. Ordinarily, plants are harvested by a mechanical device and transported to the shore, where other mechanical devices collect the harvest and either deposit it there or transport it elsewhere for disposal or use.

The types of machinery used for harvesting aquatic weeds have been described by Livermore and Wunderlich (1969) and Nichols (1974). Choice of such equipment as harvesters, transporters, and weed ploughs depends upon: (1) the type of plant to be harvested, (2) the type of water body, (3) the debris or other foreign matter encountered, (4) the nature of the shoreline, (5) the prevailing weather conditions, (6) the harvesting concept utilized, and (7) the plant disposal system contemplated (3). Also of importance with regard to the objectives of management plans are: (1) cost, (2) results, and (3) ecological implications (10).

There are two main concerns with regard to mechanical controls: (1) cost including energy consumption, and (2) disposal of harvested weeds. The cost of harvesting and disposal of weeds is often prohibitive, especially when harvesting must be done on a large scale. Often, as with waterhyacinth, weeds grow almost as fast as they are harvested, so that harvesting must begin again shortly after an area is cleared.

Water constitutes approximately 90% of the weight of aquatic weeds, and when harvested, a relatively large amount of water may be removed from a heavily infested system. Also, the heavy weight and large volume of the weeds make them difficult to transport from their point of origin. Nevertheless, research is being done to make aquatic weeds useful, and if it is successful, harvesting may become an economically feasible method of aquatic weed control. (7,8).

There are no mechanical harvesters available for algae, nor are there any processes available for making algae useful economically.

Habitat manipulation for control of aquatic weeds includes such procedures as: water level manipulation, dredging, artificial shading, nutrient limitation and inactivations, and gravel, sand, and other types of blanketing. Habitat manipulation limits growth by alteration of one or more physical or chemical factors required by plants. Two methods were discussed at the meeting as immediately feasible: water level manipulation, and use of fiberglass screens as blankets on the hydrosoil.

Mechanical control was the first control method used for waterhyacinths in Florida and Louisiana around the turn of the century. Over the first 50 years or so of this century, several chemicals were tried or actually used operationally with varying degrees of success. Some were toxic to humans and non-target organisms, whereas others were not effective or were too expensive. Since chemicals did not afford adequate control, hyacinth control, until 1950, was mainly by mechanical means, i.e., booms and traps to prevent spread by drifting.

Since 1948, various combinations of mechanical harvesting systems have been tested by several agencies, the Florida Game and Freshwater Fish Commission conducting most of the initial tests with mechanical methods for control of waterhyacinth. The Commission designed and built two types of control devices: one was a fixed-point take out that allowed plants to drift with wind and currents until they were piled on the shore; the other was designed to macerate the plants and pump the macerate through a pipe to shore or back in the water.

Neither method was highly successful, and since these early beginnings, very few mechanical systems have been used continually in the state of Florida. Neither private enterprise nor governmental agencies has helped to develop mechanical control systems because (1) they are too expensive in terms of dollars, labor, and fuel, (2) control over a large area is slow when compared to chemical control, and (3) they are inflexible, i.e., each piece of equipment, or configuration of equipment, is designed to work at a specific site under certain environmental conditions. Mechanical control is further complicated by the size and cumbersomeness of the equipment, need for trained personnel, easements, disposal areas, support logistics for fuel and transportation of personnel, and a myriad of other complicating factors.

Overall, mechanical harvesting presents managerial problems that chemical spraying does not, but the method has some positive atributes, particularly the rapid removal of plants in a limited area:

1. When harvested, a plant is gone immediately; when sprayed with a herbicide or treated with a pathogen or insect, it may persist in a decomposing state for some time.

2. There are no potentially harmful materials, except for small amounts of oil or hydraulic fluid, added to the water during harvesting, and the method is generally considered to be environmentally acceptable.
3. Although as yet unproven, it is possible that mechanical removal of some aquatic weed species allows for recolonization by less pestiferous species.

There is a need to investigate alternate means of mechanical control in order to offset adverse effects of herbicides and to be ready if effective herbicides are denied for use in aquatic systems in the future. In 1975, the U.S. Army Corps of Engineers, Jacksonville District, began a program that had two goals: to evaluate currently available equipment, and to encourage design and development of new equipment whose use would be more economically feasible than that available now.

The U.S. Army Corps of Engineers, Waterways Experimental Station, is continuing to encourage design of new harvesting systems and ecosystem simulation models that could aid in their design. It is estimated that approximately 75 per cent of hyacinths in the St. Johns River are unreachable by conventional harvesting equipment. Simulation models will aid in determining how to remove the plants, where to deposit them, and how long it will take for them to deteriorate.

EFFECTS OF MECHANICAL HARVEST

1. **Effects of mechanical control on dispersal of weeds.** Eurasin watermilfoil and hydrilla propagate by fragmentation, i.e., pieces break from the stock and may develop into complete plants. Any two-stage operation of cutting and collection is bound to cause fragmentation, which for eurasian watermilfoil and hydrilla is a highly significant means of dispersal. Cutting and collection may compound problems with these weeds. However, in a single step operation of collection only, dispersal by fragmentation may not be significant.

2. **Time of harvesting.** The time of year in which weeds are harvested may be important. There is evidence that it is best to cut and harvest some weeds in the fall for long-term control. However, research in this area is needed for the major weed species.

3. **Concepts of "aquatic plant control" and "aquatic plant management."** It was suggested that aquatic weeds need not simply to be controlled, but that the problem should be approached in a broad management scheme. This scheme would include harvesting, disposal, commercial use of harvest, and multiple harvests to control buildup of nutrients in some lakes.

4. **Disposal of harvested weeds.** The cost of weed disposal is often great, and makes mechanical harvesting economically uncompetitive with chemical control. However, in some cases, the harvest may be disposed of in the lake or reservoir itself and this would decrease cost. Actually, when herbicides are used, the plants decompose in the water. Harvest may be returned to the general water mass after shredding or it may be baled and deposited on the shore. Research is needed on effects of both types of disposal. One experiment has been tried in Orange Lake in Florida: baled material placed on shore decayed quickly without apparent detrimental effects. It would be well to know how to bale weeds so that they sink to the bottom and decay there.

5. **Harvesting of weeds as a method for removal of nutrients from aquatic systems.** Removal of weeds may be an effective method for removal of nutrients in some lakes. Four or five harvests may cause significant decrease in nutrients in an oligotrophic lake, whereas it may have little or no effect in eutrophic systems or where waters contain naturally high concentrations of nutrients.

6. **Utilization of harvested weeds.** If aquatic weeds are to be utilized economically, there is a need for development of commercial products. These products will have to utilize the plant material after the water is removed (aquatic plants are at least 90% water, by weight). Fresh aquatic plants are very heavy, and the cost of hauling harvest overland to a processing plant is great. An analogy has been drawn between catfish forming and weed harvesting. However, catfish are raised in special ponds. Profit from any commercial product will not lower the cost of mechanical field operations and hauling, so the total cost of harvesting, hauling, and preparation of product have to be considered.

Recommendations

Several mechanical devices are used for weed control. The following is a list of them and what research needs to be done.

Type of Control	Used Currently	Needs additional Testing
Harvester	Aqua-marine1/, 2/; Aqua Trip; Altostar System1/, 2/	Limnos Limited System1/, 2/
Dredging	-	Water-Vac System1/, 2/
Bottom	Fiberglass2/ screens	Vacuum maintenance of screens1/
Screening		
Rotovatory	Rotovators on1/, 2/ tractors & boats	-

1/ Research is needed on the environmental effects of water disposal of plant material when using this method.

2/ Research is needed with regard to ecological impacts of this method. Impacts include effects on nutrient cycling, food chain dynamics, bottom stabilization, and water quality characteristics.

INTEGRATED CONTROL

Integrated control of aquatic plants utilizes methods of chemical, biological, and mechanical control concurrently or sequentially in a systematic program for initial biomass reduction and long-term maintenance. It has two purposes: effective control, and minimal environmental impact by reduction of unwanted effects of any single method. The latter is achieved through synergistic interactions of methods applied at rates below those when each is used singly. For example, there is evidence that herbicidal treatment for biomass reduction of hydrilla, followed by introduction of grass carp for maintenance, will reduce the need for repeated herbicidal treatment and have little or no effect on sport fishes.

Relatively little work is being done on development of methods for integrated control of aquatic weeds. Such development relies heavily upon development of other methods, but these have advanced sporadically and synchronously. Methods for use of insects and plant pathogens in integrated systems will probably take the longest time to develop, whereas integration of chemical, mechanical, and fishes offers the best opportunity for short-term development.

Possible Methods

1. **Integrated control programs and the U.S. Army Corps of Engineers.** The U.S. Army Corps of Engineers does not have major programs in integrated control. It considered using chemical, biological, and mechanical methods, together or

sequentially, but found their developments were not synchronized. It will be at least two years before the Corps is ready to begin major research efforts in integrated control.

2. **Herbicide treatment followed by stocking with fish.** Two projects are being done on reduction of plant biomass with contact herbicides and subsequent control by grass carp or hybrid carp, but more work needs to be done in this area. The U.S. Army Corps of Engineers is also doing studies on effects of herbicide residues on stocked fish. For example, fish that are stocked after treatment with Komeen are being examined for effects of copper on survival and behavior.

3. **Herbicide treatment followed by application of pathogens.** It is a distinct possibility that stress of plants by herbicides followed by treatment with pathogens will allow proliferation of the pathogen. The herbicide may cause physiological changes in the plant that allow the pathogens to cause disease. Application of a slow-release herbicide followed by the pathogen should be investigated. Essentailly, this approach is an attempt to induce an epidemic.

4. **Mechanical harvesting followed by stocking with fish.** Mechanical harvesting is a good method for rapid removal of weeds. If followed immediately by stocking with fish, desired biomass of plants might be maintained. Methods for this approach should be developed.

5. **Mechanical harvesting and/or destruction followed by application of pathogens.** Harvesting or mechanical injury

to weeds may cause them to be more susceptible to plant pathogens, but this needs to be investigated.

6. **Treatment with insects followed by application of pathogens.** Insects that feed upon, or lay their eggs in, aquatic plants may cause lesions that allow entrance of pathogens. Effects of insects should be studied to learn if lesions caused by them aid in establishment of plant diseases.

7. **Competitive plants.** Theoretically, once weed biomass is reduced by mechanical or chemical means, desirable plants that compete with them could be planted, with subsequent growth of the desired plants and suppresssion of growth of weeds. Little is known of this potentially useful integrated method, and developmental studies should be started.

Recommendations

Recommendations for use of two-method systems are outlined in Table 1. However, integrated control eventually will use combinations of the other three types of control. Table 2 gives combinations of methods that can be used in the near future. They are ranked in relative order of how rapidly they can be developed, their importance to regions in the United States, and environmental campatibility. Since EPA's program will exist for only a few years, it is recommended that programs be funded primarily in the categories that will prove most effective in the short-run. However, ranking for combination of three methods does not apply in any way to combinations of two methods given above.

Table 2. Ranking, in relative rapidity of development, of combinations of methods that can be used for integrated control of aquatic weeds.

Overall Rank	Method	Availability of data	Environmental Compatibility	Plant type	Region
1	Chemical + Mechanical (drawdown)	1	2	submerged 1 emergent 2 algae 2	SE 1 NE 1 MW 1 West 1
2	Chemical + Mechanical + Fishes	1	1	submerged 1 emergent 1 algae 2	SE 1 NE 4 MW 2 West 2
3	Fishes + Mechanical (drawdown)	1	2	submerged 1 emergent 2 algae 2	SE 1 NE 4 MW 2 West 2
4	Chemical + Mechanical + Competitive plants	3	1	submerged 3 emergent 3 algae 4	SE 3 NE 3 MW 3 West 2
5	Chemical + Insects + Pathogens	4	2	submerged 3 emergent 2 algae 4	SE 3 NE 4 MW 4 West 4

Table 1. Summary of status of combinations available for integrated weed control using two methods.

	Chemicals	Pathogens	Insects	Hybrid carp	Grass carp	Mechanical	Drawdown
Chemicals	-	B	B	B	A	A	A
Pathogens	-	-	A	C	C	C	C
Insects	-	-	-	C	C	C	C
Hybrid carp	-	-	-	-	-	C	C
Grass carp	-	-	-	-	-	B	A
Mechanical	-	-	-	-	-	-	A
Drawdown	-	-	-	-	-	-	-

A - Now available or available within the next year.

B - In testing phase but requires more research.

C - Methods for these combinations should be developed.

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