Mechanical Harvesting of Aquatic Plants

Benjamin P. Sperry[1], William T. Haller[2], Jason A. Ferrell[3]

[1]Research Biologist, US Army Engineer Research and Development Center, Gainesville, FL; [2]Professor Emeritus, University of Florida Center for Aquatic and Invasive Plants, Gainesville, FL; [3]Professor and Director, University of Florida Center for Aquatic and Invasive Plants, Gainesville, FL.

Introduction

The U.S. Army Corps of Engineers (USACE) has over a century of experience in all methods of invasive aquatic weed control following congressional passage of the Rivers and Harbors Act of 1899. Support for this legislation in southern states was largely due to the introduction of the floating exotic waterhyacinth at the turn of the century. The USACE had access to few herbicides during this time and the ones available were inorganic toxins such as arsenic and mercury. Unlike modern herbicides, these chemicals were poisonous to applicators, cattle, and wildlife. Therefore, USACE efforts were primarily concentrated on mechanical control. Engineers designed, built, and tested scores of varying mechanical methods to control waterhyacinth including chopping, shredding, harvesting by large barge/dragline combinations, shore and barge mounted conveyors, saw boats, and many other mechanical means to drag, pull, lift, or throw tons of plant material to shore in order to open navigation channels and harbors. While this equipment was in use daily, re-infestation and rapid growth of waterhyacinth in wetland, other shallow waters, and uncleared areas quickly moved into previously cleared channels. See Gallagher and Haller (1990) for a review of public laws and operations of the USACE and other Federal and state agencies during this time period.

The development of new, less toxic, and biodegradable organic herbicides allowed aquatic plant managers to control aquatic weeds with unprecedented speed and precision. These developments have minimized the chance for invasive plants to develop populations that interfere with navigation. Additionally, proactive management of invasive plants preserves the ecosystem by preventing the smothering or uprooting desirable native plants. Thus, through a combination of herbicide use, introduction of biocontrol stress agents, and use of mechanical removal following floods or other storm events, waterhyacinth populations have been maintained for many years at low levels of infestation. In turn, this has increased overall plant diversity and minimized environmental damage caused by excessive weed growth.

Characteristics of Major Invasive Aquatic Weeds

The biology of aquatic weeds and the characteristics of the sites they are found in need to be understood when planning management operations. These parameters are particularly important with mechanical control since plant biomass, plant movement (floating plants), shoreline placement of equipment, conveyors, trucks, and disposal sites all need to be considered. In general, target weeds can be broadly divided into three categories: free-floating plants, submersed plants, and floating islands or tussocks.

Free-floating plants.

The majority of free-floating plant management in the U.S. targets waterhyacinth and waterlettuce. These two species produce viable seeds; however, their primary means of reproduction is by rapid production of vegetative ramets or daughter plants. Vegetative reproduction, which in the case of waterhyacinth means they can produce a new plant every 5 to 7 days under ideal growing conditions, results in exponential population expansion. This means that plants are theoretically capable of doubling the population each week, or a single plant infesting an acre (500,000 plants) in just 5 months. In the warmer regions of the Gulf Coast states, growth can occur throughout the year. In addition to their exponential growth rate, these plants are also mobile and move with wind and water currents. Plant mobility is problematic because plant biomass can accumulate and cause blockages at pinch-points in rivers, or move to inaccessible sites such as flooded timber, swamps, and shallow water areas. These sites are often inaccessible for harvesting due to shallow water depths or physical obstruction such as trees and levees. Consequently, due to their growth rate and high mobility, free-floating plants require frequent management to maintain populations at low levels.

An important consideration in mechanical harvesting operations is the weight of material being removed. Waterhyacinth fresh weight typically ranges from 50 to 300 tons per acre (average = 150 tons per acre) depending on plant size and density. Likewise, populations are commonly found at densities of 8 to 10 plants per ft^2 or 350,000 to 450,000 plants per acre. Fresh biomass of these plants is approximately 95% water. Therefore, an average biomass of 150 tons per acre is equivalent to 7.5 tons of dry weight and 32,300 gallons of water. These heavy weights increase strain on equipment and require frequent unloading which results in longer hours and increased costs. Moreover, the harvest operation applies seismic stress to the floating mat, causing plants along the periphery to break off and float in various directions. It is estimated that as much as 20% of the intact mat will be scattered, further reducing efficiency. Due to these factors, mechanical harvesting of free-floating plants is extremely challenging.

Contracts for mechanical harvesting are commonly based on hourly rates and very little information exists to accurately calculate costs on a per acre basis for free-floating plants. Also, because these plants constantly move via wind and water currents, quantifying actual acres harvested is almost impossible. A contract for mechanical harvesting performed at Lake Kissimmee, FL listed an average cost of $2,200 per acre. Conversely, free-floating plant control with herbicides typically costs between $100-200 dollars per acre (15 year average; labor plus chemical cost). Mechanical harvesting of floating plants will ideally cover 1.5-2 acres per hour, whereas herbicide application boats can cover up to 7 acres per hour.

Submersed plants.

Hydrilla and Eurasian watermilfoil were both introduced into US waters in the mid-20th century, likely by the aquarium plant trade. Hydrilla rapidly became problematic in the southern US and is now considered the most widespread aquatic weed in the country. Eurasian watermilfoil is most problematic in the northern US. Both plants can reproduce by seed, but even small fragments of the plant can form roots and initiate new vegetative growth, which is the primary means of regrowth following management operations. Both plants have similar characteristics and are widely considered capable of growing an inch per day under average growing conditions. Thus, these plants can regrow to the water's surface in a period of 50 to 70 days following mechanical clipping at typical depths of 5 feet. Growth rates are limited by light penetration in the water. However, these plants are both physiologically adapted to low light conditions and are commonly found growing to water depths of 12 to 15 feet (or more). This provides a significant competitive advantage since most native submersed plants cannot survive at these low light levels. Milfoil is typically a seasonal problem in northern states; however, hydrilla grows year-round in the southern US.

Submersed plants typically produce much less biomass, per acre, than floating or emergent species since they are limited by light penetration and carbon dioxide compared to their terrestrial counterparts. Submersed plants contain approximately 15-fold less biomass than waterhyacinth which allows mechanical harvesters to cover more acreage before unloading. On average, submersed plant fresh weight is approximately 10 to 15 tons per acre (average = 12 tons per acre) when growing at the water surface. Like free-floating plants, submersed plants also contain ~95% water so each acre consists of approximately 1,200 lbs of dry material and 2,860 gallons of water.

Mechanical harvesting of submersed plants has been evaluated many times and is currently used in select areas today. In northern states, harvesting of submersed plants like Eurasian watermilfoil and curlyleaf pondweed is common and effective for small areas. However, harvesting of submersed plants like hydrilla in southern states is often cost-prohibitive due to the longer growing season, large-scale infestations, and operation costs. Though harvesting will provide rapid control of submersed plants, the effects are temporary as regrowth occurs shortly after treatment (Johnson and Bagwell 1979; Painter 1986). Consequently, repeated harvests are required per season to keep plants suppressed. Unlike other forms of submersed plant control, mechanical harvest is largely non-selective and affects desirable native plants in the treatment area as well. Furthermore, harvesting also results in by-catch. While the by-catch in mechanical harvesting operations primarily consists of small fish, other organisms such as reptiles, mollusks, amphibians, and insects can also become trapped by harvesters (Booms 1999; Engel 1990; Haller et al. 1980; Wile 1978).

Tussocks, Floating Islands, or Flotons.

These are highly diverse mats of floating vegetation or emergent vegetation attached to highly organic lake bottom soils, but both can be a serious impediment to navigation by blocking channels, flood control structures, pump stations, and locks. These are either pushed out of high-use areas or mechanically removed by back-hoes, draglines, or very large mechanical harvesters. In northern states small mats of floating emergent vegetation, such as cattails, are often broken away from their shallow locations by high wind or water events. In highly organic bottoms of lakes and reservoirs, particularly in southern states such as Florida and Louisiana, these mats form during periods of drought and low water conditions and consist of wetland plants growing and making extensive root systems in the lake bottoms. Subsequent rising water pulls the roots, with soil still attached, to the water surface where wind and water currents move them to structures, boat ramps, and navigation channels where removal is costly due to the weight of the plant biomass. These mats may also accumulate in wetland areas where state agencies are concerned about impacts to fish spawning sites. Mats in these locations are typically chopped up or otherwise mechanically removed to improve fish habitat. Tussock weights widely vary depending on size, plant types, and the quantity of attached soil. For more information, Mallison et al. (2010) discusses tussock control and plant succession on Orange Lake, FL.

Tussock removal has been the most common use-pattern of mechanical harvesting in the last 50 to 60 years. These operations are largely viewed as environmentally neutral; however, tussock harvesting can result in temporary increases in water turbidity (Alam et al. 1996). Costs for these operations commonly range from $3,000 to $12,000 per acre depending on treatment area size, vegetation type, accessibility, distance to disposal sites, etc. Very rarely are these contracts established at a fixed price per acre. Alternatively, hourly rates are common, and as mentioned above, differ depending on the site and specific goals.

Site Characteristics

The type of weed to be harvested is a critical element in evaluating the feasibility and potential cost of mechanical harvesting operations; however, site characteristics are equally, if not more important. Almost all mechanical harvest operations require additional equipment such as elevators, conveyors, backhoes, and/or dump trucks operating on shorelines. Aquatic plants contain excess water which constantly drains from equipment and shorelines quickly become muddy and rutted. Thus, the offloading or transfer site must be dry and, in most cases, public concrete boat ramps are the preferred locations for transferring plants from the water to shore disposal sites. Other important site considerations include:

- Closing and/or constructing suitable shore transfer sites.
- Area to be harvested. Since one machine may only be able to harvest and maintain 300 to 500 acres and additional harvesters may be needed to maintain navigable waters, additional shore transfer site equipment may be needed.
- Distance from the harvesting site to the shore transfer site. Large distances require additional harvesters or shuttle barges.
- Distance from the shore transfer site to the final dump site. Large distances may require additional trucks.
- Potential tipping fees at landfills.

- Water depth at harvesting site as loaded harvesters often require 18 to 36 inches of water to operate at maximum efficiency.
- Turbidity may increase in shallow water, though research has shown it is only temporary
- Location of weeds to be harvested. Studies on Lake George Florida indicated a major portion of waterhyacinth plants were located in shallow, shoreline areas around cypress trees that were inaccessible by harvesters.
- Possible stump field in reservoirs.
- Prevailing wind direction. Wind and water currents can move floating plants significant distances from the harvest site and are difficult or impossible to push back to the site.
- Water flow. Harvesting commonly results in loose plant fragments which can flow downstream to infest other sites or pile up on private beaches.
- Potential by-catch of fish and other fauna at certain times of the year (potential threat to endangered or threatened species).
- The more times vegetation is handled increases time spent and cost of the overall project

Utilization of Harvested Vegetation

Extensive studies have been conducted over the years to find a viable end-use of this vegetation with the potential to offset management costs, but there are no large-scale uses known at this time. Residents in rural areas of developing countries use these materials for small-scale purposes such as mulch for growing mushrooms or other garden crops, small scale bio-fuel generators, etc. It is important to remember that these plants are approximately 95% water and drying them is labor intensive (solar drying) or costly process (pelletizing for incorporation into cattle feed). Other uses that have been evaluated include:

- Cattle or animal feed. Products made from aquatic plants were not highly prized due to high calcium and silicon content which can cause health issues in ruminant animals. Additionally, water content was too high for ensiling without acidifiers and other additives. Furthermore, market competition from terrestrial crops was too high among other economic issues.
- Pulp/paper/fiberboard. This is totally non-feasible for submersed plants as these plants have no cellulose. Waterhyacinth has been considered; however, these plants have low fiber content and fibers that are produced are short. Current paper production equipment cannot effectively process these short fibers compared to wood pulp which has long fibers and a much greater fiber content.
- Mulch/fertilizer. This use is implemented on a small scale in developing countries. However, costs of sphagnum mosses, wood mulch, commercial fertilizers, and other products are lower, which disincentivizes using aquatic plant materials. Based on nutrient content, about 45 acres of harvested waterhyacinth plants would be required to provide a single ton of phosphorus at a cost several orders of magnitude greater than commercial products.
- Biofuels. This was evaluated for several years with waterhyacinth on a large scale at the City of Orlando, Iron Bridge Sewage treatment plant. The conclusion of the project was that biofuels were not commercially viable. Although, this process is used on a limited basis in rural areas where residents use metal drums to mix plants with cattle dung to produce gas for cooking purposes. See Vietmeyer (1976) for further information.

Case History – Hydrilla Harvesting on Orange Lake, FL

The USACE Jacksonville District, in cooperation with US Army Engineer and Research and Development Center, evaluated the state-of-the-art Aqua-Trio system for hydrilla control on Orange Lake

Fl in 1977 (Culpepper and Decell 1978). Orange lake is a shallow 10,000 to 12,000-acre lake in north central Florida that was 90% covered by hydrilla in 1976-77. This infestation caused severe economic hardship for the local economy that rented rooms, boats, and sold supplies to recreational anglers on this famous fishing location. No boats could navigate the dense submersed hydrilla mats and fishing near shore was impossible. The Aqua-Trio system consisted of a harvester, transport barge, shore conveyer, and a dump truck to dispose of the harvested material in a nearby abandoned citrus grove.

McGehee (1979) reported that a single harvester was able to maintain 160 acres of navigable trails and fishing areas by removing 1,100 harvester loads over a 4-month period (94 workdays; 22 June to 28 October). A total of 1600 tons of hydrilla was removed (10 tons per acre). Some trails had to be cut six times in this period to maintain navigation, while others more commonly were cut two to three times. The plant biomass in the re-cuts was less than the original cuts. Low water levels in the latter half of the project prevented use of the shore transfer site, so harvester loads were deposited in shallow areas along the un-developed shoreline which doubled the production of the harvesting process. The final cost was \$550/acre (~\$2,400 per acre in 2021) for the 160-acre area of the lake harvested. In perspective, this area was maintained by one harvester operating 5 days a week in a lake with 9,000 acres of hydrilla with one shore transfer site. Larger and more efficient harvesters are now available, but to maintain even a 1,000-acre area will likely require more than one harvester.

Advantages and Disadvantages to Mechanical Harvesting

Advantages:

Nutrient removal. Mechanical harvesting removes nutrients from the water body. This can be temporary or long-term depending on where the materials are deposited. While the magnitude of nutrients is usually insignificant compared to nutrient inputs to a given system, other control techniques do not remove nutrients (Peterson et al. 1974).

Immediate results. Unlike other forms of aquatic plant management, mechanical harvesting is effective immediately as operations provide rapid control of the target plant compared to chemical or biological control.

Habitat. For harvested submersed plants, fish habitat remains after treatment and plants regrow from rooted sections.

Reduction of carbon in the system. Plant materials removed in mechanical harvest operations are not left in the system to contribute to sedimentation. Likewise plants that are removed do not decompose in the water column and dissolved oxygen is not usually reduced.

Precision of treatment. Plants are only managed where harvesting treatments are implemented.

Public perception. Mechanical harvest is largely viewed as environmentally friendly by the public and widely accepted.

Disadvantages:

Water quality. In some scenarios (e.g., shallow eutrophic lakes of Florida) paddle wheel-driven mechanical harvesters that require 2 to 3 feet of draft on average, resuspend nutrient-rich sediments which can result in temporary periods of increased turbidity or algae blooms.

Reduced efficiency. On average, a single harvester can only harvest 0.25 to 1.5 acres per hour depending on targeted material. Consequently, numerous harvesters would need to be dedicated in each lake in Florida to keep plant populations under control. In some areas and other states, this limits the utility of mechanical harvesters largely to small boat trails or swimming sites.

Draft vs. speed – harvester size implications. The conventional harvester drafts approximately 2 feet of water or more depending on payload. However, if payload capacity needs to be greater for harvesting materials such as floating and emergent plants on tussocks, larger harvesters are needed. Unfortunately, the larger the harvester, the deeper the draft. Smaller harvesters have been utilized to account for shallow water; however, shallow water harvesters are much smaller and cannot carry as much weight. These implications are directly associated with transport time and harvesting speed.

Species selectivity and by-catch. Mechanical harvesting is largely non-selective and desirable native plants are negatively affected. Likewise, as mentioned above aquatic fauna can be impacted by operations as well.

Duration of control. For most aquatic plants, mechanical harvesting only provides temporary control as plants grow back quickly after treatment. For example, hydrilla harvested to a 5 foot depth can regrow to the water surface in as little as 2 months depending on treatment timing and water quality parameters.

Pollution risk. Cases of leaking diesel fuel, gasoline, or hydraulic fluids from mechanical harvest operations have been documented which have resulted in fish kills and deleterious environmental effects.

Off-site deposition. Transportation and disposal of harvested materials is one of the most expensive and difficult components to mechanical harvesting operations.

Cost. Since the advent of modern herbicides, mechanical harvesting has been the most expensive management option for most aquatic plant management goals.

Conclusion

Mechanical harvesting is an aquatic plant management tool that has been utilized for over a century in the US and is still used today. Like any tool, mechanical harvesting has advantages and disadvantages. However, it is not advisable to limit management options to a single tool for all problems. Alternatively, integrated management of aquatic plants including biological, mechanical, chemical, and cultural control techniques must be utilized.

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