Making Aquatic Weeds Useful: Some Perspectives for Developing Countries

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NATIONAL ACADEMY
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Some Perspectives for Developing Countries

Report of an Ad Hoc Panel of the
Advisory Committee on Technology Innovation
Board on Science and Technology for International Development
Commission on International Relations

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Avec Résumé en Français

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Panel on Utilization of Aquatic Weeds

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Preface

For over a decade, the National Academy of Sciences–National Research Council (NAS–NRC), through the Commission on International Relations and its Board on Science and Technology for International Development (BOSTID), has devoted attention to the application of scientific and technical resources to problems of international economic and social development.* In 1970, BOSTID established an Advisory Committee on Technology Innovation (ACTI) to assess new scientific and technological developments that might prove especially applicable to problems of developing countries. This report was produced by an *ad hoc* panel of that committee, the Panel on Utilization of Aquatic Weeds, composed of botanists, engineers, and animal scientists, which met in Gainesville, Florida, in November 1975.

The problem that the panel considered was the vast infestations of aquatic plants that burden waterways, interfering with navigation, irrigation, disease and insect control, fisheries production, and water quality.

Aquatic weeds have always existed, but in recent decades their effects have been magnified by man's more intensive use of natural water bodies—his modifying them into canals and dams, polluting them with farm and city wastewaters, and introducing aggressive plant species into new locations. These plants, among the most prolific on earth, grow luxuriantly in the tropics, weigh hundreds of tons per hectare, and can be a serious hindrance to a nation's development efforts. Eradication of the weeds has proved impossible, and even reasonable control is difficult. Turning these weeds to productive use would be desirable, but only limited research has so far been carried out.

This report examines methods for controlling aquatic weeds and using them to best advantage, especially those methods that show promise for less-developed countries. It emphasizes techniques for converting weeds for feed, food, fertilizer, and energy production. It examines, for example, biological control techniques in which herbivorous tropical animals (fish, waterfowl, rodents, and other mammals) convert the troublesome plants directly to meat.

*These activities have largely been supported by the U.S. Agency for International Development (AID). This report was sponsored by AID's Office of Science and Technology, Bureau for Technical Assistance.

In many situations, use of the aquatic weeds will contribute markedly to their control; thus, most of the methods discussed represent potential control techniques. However, this is not a report on aquatic weed control *per se*. Many of the techniques described will make little visible difference to massive aquatic weed infestations; furthermore, there is no discussion of herbicides, or of such biological controls as insects and pathogens that kill the plant but do not produce a useful by-product. This is not to denigrate such techniques. Indeed, in any aquatic weed control program that aims for long-term control, they will almost always be needed as adjuncts to a utilization program. There is, however, extensive literature on control techniques, and the panel felt that it could best serve by reporting on what has thus far received far too little attention—the productive use of aquatic weeds. Marine and estuarine plants are excluded from the discussion, and algae are not stressed.

None of the techniques described is a panacea; none is able to *eradicate* aquatic weeds from infested waterways. They should be seen as useful tools in an integrated system of weed management in which different control techniques complement each other and produce a usable product. For example, in some locations chemicals may be used to reduce a large infestation before a herbivorous animal, such as the manatee described in this report, is introduced. In this case, the animal's role would be to retard regrowth and maintain the waters weed-free.

The advantage of weed utilization over chemical and many biological weed controls (e.g., insects and pathogens) is the production of valuable end products: meat, eggs, fish, edible vegetation, fertilizer, animal feed, energy, paper pulp. Readers should appreciate that although the methods are cataloged independently in this report, in many—perhaps most—situations, combinations of several methods (or combinations of weed utilization with other weed-control techniques) may be the best way to benefit from the weeds while still maintaining a waterway's value for navigation, fishing, etc. Using a single method often encourages those weeds that are unaffected by, or resistant to, the method. The new weeds may produce more serious and less tractable problems.

Though the techniques described in this report have been selected for their applicability in less-developed countries, many are relevant to industrialized countries. Both types of country face a future in which food production will need to depend more and more on the effective management of natural systems, such as waterways.

This report purports only to be an introductory review of its subject and not a technical treatise. It is directed to the attention of those whose resources and commitment are needed to stimulate and support research on aquatic weed utilization.

For the convenience of the reader, each topic is presented in a separate chapter arranged in the following order:

- Description of the technique and of its advantages
- Limitations and special requirements
- Research needs
- Selected readings (significant reviews, general articles)
- Research contacts (individuals or organizations known by panelists to be involved in relevant research and who have agreed to provide readers with further information if requested)

However, the subject matter of Chapters 6 (Other Herbivorous Animals), 7 (Harvesting), and 14 (Aquatic Plants for Food, Miscellaneous Uses) do not lend themselves to this format, and these chapters use a different style.

Photographs are provided to give nonspecialist readers who scan the report a sense of its contents; a summary of each chapter is given on page 2; and, in each chapter, the early paragraphs are nontechnical and discuss the technique and its apparent advantages. In most chapters the later paragraphs contain more technical information of the kind needed by researchers and technical personnel to decide on the chapter's relevance to their country's specific situation and needs. In this way it is hoped that the report can introduce decision makers to aquatic weed utilization while at the same time providing their technical advisors with the details they need.

In its discussion of the utilization methods, the panel took heed of economic parameters but could not consider these in specific detail. Attempts to estimate future cost in the vastly different economic and ecological environments of the several dozen countries beset with the problem of aquatic weeds would have bogged down the discussions, as would consideration of political, institutional, and social factors. Accordingly, this report confines itself to a technical overview, leaving to the reader the task of weighing the technical prescriptions in light of his country's resources and capabilities. Readers should recognize that some of the techniques described may prove difficult to apply successfully to specific weeds in individual countries. Adaptive research by local scientists may be needed to achieve success. Reading lists and a list of contacts are given so that readers may explore for themselves the relevance and adaptability of the techniques to their specific location.

The panel is indebted to Dr. John Gerber and Suzanne Parker for handling local meeting arrangements in Gainesville, Florida. The report was edited and prepared for publication by F. R. Ruskin and Donna W. Shipley.

Contents

Introduction and Summary

The menace of water weeds is reaching alarming proportions in many parts of the world. Water is an important resource, and aquatic weeds affect it adversely by blocking canals and pumps in irrigation projects; interfering with hydroelectricity production; wasting water in evapotranspiration; hindering boat traffic; increasing waterborne disease; interfering with fishing and fish culture; and clogging rivers and canals so that drainage is impossible and floods result.

This is a global problem, but it is particularly severe in tropical nations where warm water and increasing numbers of dams and irrigation projects foster aquatic plant growth. Furthermore, the problem is worsened by increasing enrichment of natural waters by fertilizer runoff and by nutrients from human and agricultural wastes. In India, large irrigation projects have been rendered useless by plants that block canals, reducing water flow by as much as four-fifths. Subsistence farmers in the wet lowlands of Bangladesh annually face disaster when rafts of water hyacinth, weighing up to 300 tons per hectare, are floated over their rice paddies by floodwaters. As the floods recede, the weeds remain on the germinating rice, killing it. Panama Canal engineers have estimated that the canal would be impassable within three years without continuous aquatic weed control measures.

As aquatic weeds spread, they disperse the water snails that cause schistosomiasis, the insidious, debilitating disease prevalent in many developing nations. These snails live on the dangling roots of floating plants and ride along as wind and current float the plants around. In addition, aquatic plants foster malaria, encephalitis, and other mosquito-borne diseases because small, sheltered pools perfect for mosquito breeding are formed between the floating plants.

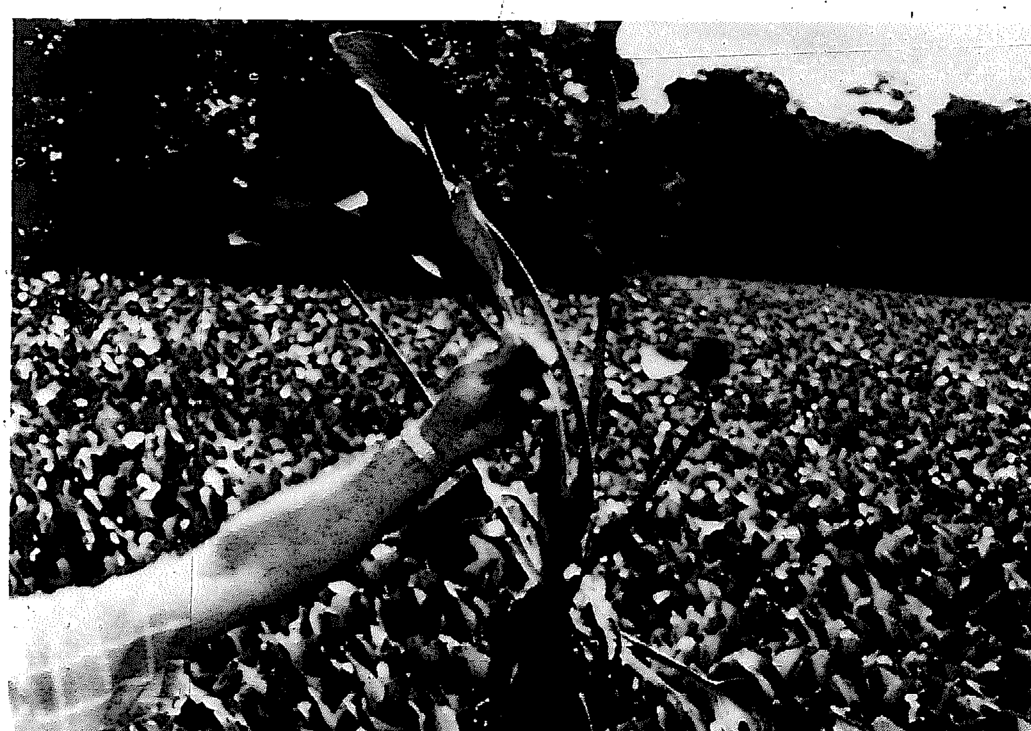
And yet, in a sense, aquatic weeds constitute a free crop of great potential value—a highly productive crop that requires no tillage, fertilizer, seed, or cultivation. Aquatic plants have potential for exploitation as animal feed, human food, soil additives, fuel production, and wastewater treatment.

As the serious negative implications of the presence of aquatic weeds are becoming more widely recognized, scientists, engineers, and government administrators are beginning to take action. Unfortunately there is no simple way to reduce the infestations. Herbicides that kill aquatic weeds and mechanical devices that harvest them are the only methods used in the developed countries. Both are expensive, and many developing countries must spend scarce foreign exchange to import them. Even when they do, chemical and mechanical methods often prove almost impossible to use because of difficulties of equipment maintenance and access to remote or swampy areas. Chemicals may also adversely affect the environment, and the masses of decaying organic debris that they produce can interfere with fish production.

This report explores an alternative: the conversion of aquatic weeds to food, fertilizer, paper and fiber, and energy. A summary of the topics discussed follows.

The Grass Carp

A quick-growing fish that lives on plants, the grass carp, whose meat is highly prized, prefers succulent submerged weeds (which are difficult to control by conventional techniques). Although the grass carp is native to cool-water rivers of China, it thrives in warm tropical waters and may attain a weight of over 30 kg. Natural reproduction seldom occurs outside its native range, but the fish can be reproduced artificially. (Chapter 1)



United States: The water hyacinth. A floating aquatic plant from Brazil that is now classified as a weed in 52 nations. (F. W. Zettler)

Thailand: The intertwined mat of water hyacinth stems makes a waterway virtually impassable to boats. (N. D. Vietmeyer)

Other Herbivorous Fish

The feeding habits of many tropical fish are barely known. A wide-ranging search for fish that eat plants and algae could locate species with important futures as aquatic weed control agents. Among known species cited as deserving research and testing are *Tilapia* species, South American silver dollar fish, and the silver carp. (Chapter 2)

Manatees

These almost extinct tropical mammals are exceptionally proficient at clearing weeds from canals. They eat many kilograms of weeds daily and will consume many different species. Until their breeding and husbandry in captivity can be developed, they will only be useful in their native Latin American and West African countries, and then only if they are protected and conserved. (Chapter 3)

Crayfish

Among the least exploited edible freshwater organisms, these close relatives of the lobster bring premium prices as gourmet food. In the state of Louisiana, crayfish are farmed on a large scale in rice fields where they feed on aquatic weeds, small aquatic organisms, and the stubble left after rice has been harvested. (Chapter 4)

Ducks, Geese, and Swans

If carefully managed, these common herbivorous animals can clear aquatic weeds remarkably well from ponds and small waterways. In so doing, they provide meat and eggs. They are particularly promising for small-farmer use in developing countries. (Chapter 5)

Other Herbivorous Animals

Many animals live on plants, but there has never been a systematic study of how to graze herbivorous animals productively on aquatic weeds. Animals worth testing include capybara, nutria, donkeys, pigs, and sheep. Recent research suggests that, if carefully managed, water buffalo will feed on aquatic plants, such as water hyacinth. (Chapter 6)

Harvesting

The wet, often marshy environment where aquatic weeds grow is extremely difficult to harvest; however, some ingenious devices have been developed to do it. A few are shown pictorially. (Chapter 7)

Dewatering

High moisture content is the single most important difference between aquatic and terrestrial vegetation. Typically, aquatic weeds contain only 5–15 percent solid matter. In order to transport or use them in animal feeds or in

Thailand: A fisherman near Bangkok attempts to find a few square meters of weed-free water to set his net. The same scene can be viewed throughout Southeast Asia. (N. D. Vietmeyer)

Sri Lanka: Water hyacinth can get so thick that it can be walked on. As in other parts of the world it interferes with the use of waterways for washing, drinking, and transport. (N. D. Vietmeyer) other products, much of the water must first be removed. Pressing the water out mechanically and removing it by solar drying are two methods now under development. (Chapter 8)

Soil Additives

Fertilizer is in critically short supply in many developing countries. Many aquatic weeds contain appreciable quantities of nitrogen, phosphorus, potassium, and other fertilizer ingredients. Because of this, aquatic weeds applied to farmland benefit crops. In addition, they improve soil texture, which is vitally important in sandy, lateritic, and heavy clay soils—all of which are widely distributed in developing countries. (Chapter 9)

Processed Animal Feeds

Fresh aquatic weeds usually have too much moisture to be efficient feedstuffs. Furthermore, many are not palatable to the major breeds of cattle and sheep. Pressing out some of the water and ensiling the residue is a promising technique for use in developing countries. Ensiled water hyacinth and other aquatic weeds have been relished even by cattle used to high-grade diets. (Chapter 10)

Egypt: A deep drainage canal at Gizeh filled with floating aquatic grasses. (N. D. Vietmeyer)

Pulp, Paper, and Fiber

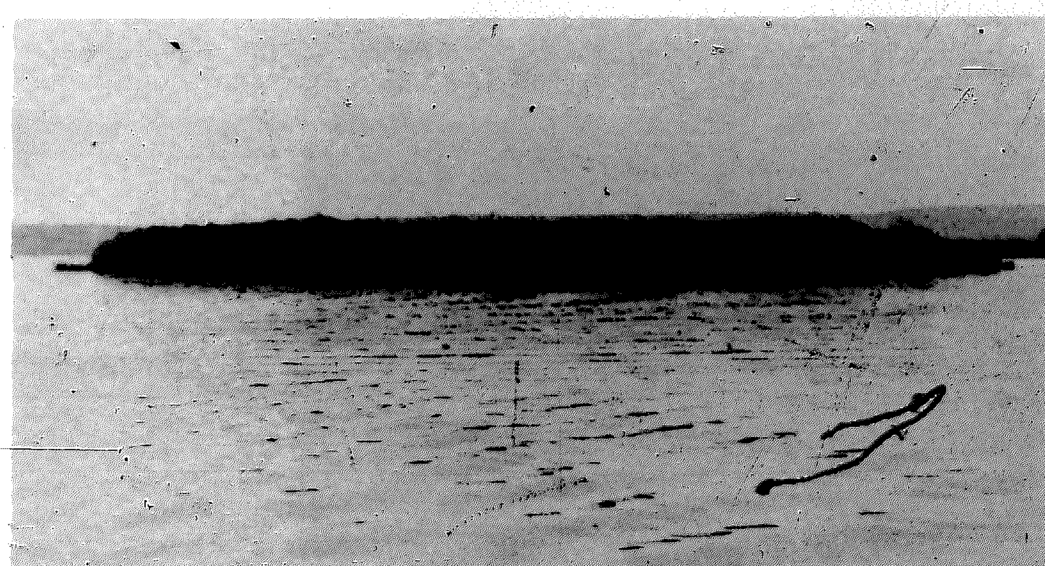
In Romania, pulp and paper are produced on a large scale from fibrous, reed-like aquatic weeds; in other parts of the world, aquatic weeds are used for thatch, furniture, mats, baskets, etc. Papyrus (source of the first paperlike writing materials), cattails, and bulrushes remain neglected but promising resources. (Chapter 11)

Energy

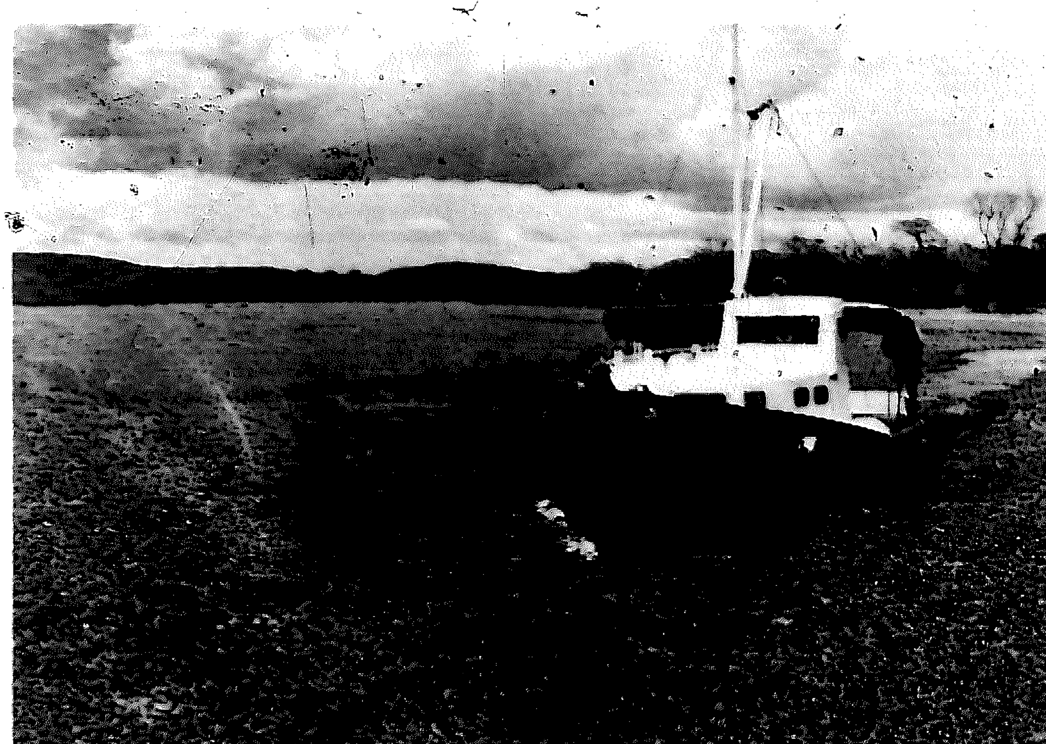
In a project in Mississippi the National Aeronautics and Space Administration (NASA, the U.S. space program) is fermenting water hyacinth to methane gas. This experimental project offers a method by which aquatic weeds could be converted to valuable fuel. (Chapter 12)

Wastewater Treatment Using Aquatic Weeds

Compounds containing nitrogen and phosphorus are common pollutants in waterways. They also happen to be major ingredients in fertilizer. Some aquatic weeds can extract these materials from water and incorporate them into their own structure. Researchers in a number of laboratories have recently found that these plants can be used to treat sewage effluent so that dissolved nutrients are recovered for reuse. Experiments are now under way to purify municipal sewage, industrial wastewater, and pig-farm and dairy wastewater by growing aquatic plants in them. (Chapter 13)



Kenya: Floating "island" of papyrus and other emergent aquatic weeds at Kisumu harbor. By blocking boat traffic and disrupting fishing such islands cause serious problems in many of Africa's waterways. (East African Railways Corporation)



Zambia: When the lake behind the Kariba Dam began to fill in 1960, the water fern *Salvinia molesta* expanded explosively across the water surface. By 1962 the weed covered an estimated 1,000 km^2, a fifth of the area of Lake Kariba, one of the largest man-made lakes in the world.

Aquatic Plants for Food, Miscellaneous Uses

Only one aquatic plant is widely used as a food crop—rice. Chinese water chestnut, watercress, and other lesser known species seem worth increased exploitation. (Chapter 14).

Background

The aquatic weeds discussed in this book (flowering species, for the most part) are generally classified as floating, submerged, or emergent. The plants most widely recognized by the public as weeds are the floating types, such as water hyacinth (*Eichhornia crassipes*), water lettuce (*Pistia stratiotes*), and salvinia (*Salvinia* spp.). The roots of these plants hang in the water and are not attached to the soil.

Weeds that grow below the water surface are called submerged. Often they form a dense wall of vegetation from the bottom to the water surface. Many submerged weeds are known, but hydrilla (*Hydrilla verticillata*) and water milfoil (*Myriophyllum spicatum*) are two of the most notorious.

Rooted weeds that extend above the water surface are termed emergent. Cattails (*Typha* spp.), papyrus (*Cyperus papyrus*), the bulrush (*Scirpus* species), and the reed (*Phragmites communis*) are of this type. Detailed information about these and other aquatic weeds can be obtained from the selected readings listed at the end of this chapter.

Productivity

Aquatic weeds are often more productive than terrestrial plants. Water hyacinth, for example, is one of the most prolific plants on earth. In one experiment, two parent plants produced 30 offspring after 23 days and 1,200 at the end of four months.* Stands of 470 tons of water hyacinth per hectare, and weight gains of 4.8 percent per day have been measured.† When grown on sewage effluent, the water hyacinth's productivity can become enormous: Growth rates of the order of 800 kg of dry matter per hectare per day have been recorded.‡

Chemical Composition

The composition of aquatic weeds is dominated by a huge preponderance of water; the dry-matter content is very low, generally from 5-15 percent. By comparison, terrestrial forages contain 10-30 percent solids.

The low level of dry matter has been the major deterrent to the commercial use of harvested aquatic weeds. In order to obtain one ton of dry matter, 10 tons of most aquatic weeds must be harvested and processed; for the water hyacinth, which is usually only 5 percent dry matter, 20 tons must be harvested and processed just to get one ton of dry matter.

In contrast to terrestrial plants, air canals in many aquatic plants form a large gas-filled intercellular system. These air canals accumulate the oxygen of photosynthesis and conduct it throughout the entire plant, particularly to the roots, which might otherwise die in the often oxygen-deficient water or bottom mud.

The chemical composition of a species of aquatic plant is markedly affected by the aquatic environment in which it grows. Water supports the weight of submerged aquatic plants so they don't develop fibrous stems. Floating plants and emergent plants require more skeletal strength in their

*Reported in Holm et al. 1969. (See Selected Readings.)

†Knipling, E. B., S. H. West, and W. T. Haller, 1970. Growth characteristics, yield potential, and nutritive content of water hyacinth. *Soil and Crop Science Society of Florida Proceedings* 30:51-63.

‡Wolverton and McDonald, 1976. (See Selected Readings.)

aerial parts and have more fiber than do most submerged plants. Floating plants have spongy leaves and stems for flotation.

Nitrogen Content

Aquatic weeds are generally between 10 and 26 percent crude protein (on a dry-matter basis)—a range similar to that found in terrestrial plants. In water hyacinth, water lettuce, and hydrilla, at least 80 percent of the total nitrogen is in the form of protein. In other species the percentage is probably similar. Individual amino acids are present in amounts like those reported for land forages of similar crude-protein content. But the levels of methionine and lysine—generally considered the limiting amino acids in plant proteins—are often lower than in terrestrial crops.

Mineral Content

Ash content of aquatic weeds varies with location and season much more than it does in land forages. Sand, silt, and encrusted insoluble carbonates from the water often account for much of the mineral content. Although silt can be washed off the plants, in practice it represents part of the chemical composition of the harvest. The amount of minerals varies from 8 to 60 percent of the harvest (dry weight), depending on the waterway's chemical content and turbidity.

Mexico: Water hyacinth covers a lake at the Presa Endó, near Tula. (B. D. Perkins)

The amounts of phosphorus, magnesium, sodium, sulfur, manganese, copper, and zinc in aquatic weeds growing in nature are generally quite similar to those in terrestrial plants. However, aquatic plants are often richer in iron, calcium, and potassium than land forages, and some species are known to concentrate such minerals to very high levels. The amounts of all mineral elements can be exceptionally high in aquatic plants grown in sewage or agricultural and industrial wastewater.

Miscellaneous

Some aquatic plants have carotene and xanthophyll pigment concentrations that equal or exceed those of terrestrial forages such as alfalfa. These pigments are important ingredients in poultry rations.

Pesticides have been found in aquatic plant samples collected when the waterway had been recently treated with herbicides or insecticides. Also, traces of cyanide, oxalate, and nitrate have been found, but at levels not grossly different from terrestrial grasses. No evidence of toxicity to mice, sheep, or cattle has yet been found in water hyacinth or hydrilla samples.

An aquatic weed's composition nonetheless mirrors the chemical composition of its waterway: If mining, industry, or natural rock formations add toxic minerals to the water, the weeds downstream can be toxic, even though the same species upstream are not.

Selected Readings

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Cook, C. D. K., B. J. Gut, E. M. Rix, J. Schneller, and M. Seitz. 1974. *Water Plants of the World*. Dr. W. Junk b.v., Publishers, The Hague, The Netherlands. 561 pp.

Holm, L. G., L. W. Weldon, and R. D. Blackburn. 1969. Aquatic weeds. *Science* 166:699–709.

Infoletter. Published monthly by the International Plant Protection Center, Oregon State University, Corvallis, Oregon 97331, USA. (A newsletter containing information on weed science, including new control techniques, upcoming conferences, new publications, etc. Oriented to needs of developing countries.)

International Association of Aquatic Vascular Plant Biologists Newsletter. Available c/o Dr. C. Peter McRoy, Institute of Marine Science, University of Alaska, Fairbanks, Alaska 99701, USA. (A newsletter containing much technical information on the botany and ecology of aquatic plants, both freshwater and marine. Contains abstracts of recent publications.)

Journal of Aquatic Weed Management [formerly *Hyacinth Control Journal*]. Published annually by the Hyacinth Control Society, P. O. Box 2237, Fort Myers, Florida 33302, USA. (A society devoted to the management of aquatic weeds with several hundred members from more than a dozen countries.)

Little, E. C. S., ed. 1968. *Handbook of Utilization of Aquatic Plants.* Plant Production and Protection Division, Food and Agriculture Organization of the United Nations, Rome. 123 pp. [Ordering number PL:cp/20]

Mitchell, D. S., ed. 1974. *Aquatic Vegetation and its Use and Control.* United Nations Educational, Scientific, and Cultural Organization, Paris. 135 pp.

National Council for Research. 1976. *Aquatic Weed Management: Some Prospects for the Sudan and the Nile Basin.* Khartoum, Sudan. 57 pp. [Available without charge, see p. 173 for ordering information.]

National Science Research Council of Guyana. 1973. *Some Prospects for Aquatic Weed Management in Guyana.* Georgetown, Guyana. 39 pp. [Available without charge, see p. 172 for ordering information.]

PANS (Pest Articles and News Summaries). Published by the Centre for Overseas Pest Research, College House, Wrights Lane, London W8 5SJ, England. (Often features articles relating to aquatic weeds in developing countries.)

Ratchanee, K. 1972. *Water Hyacinth Abstracts.* Published by the Applied Scientific Research Corporation of Thailand, 196 Phahonyothin Road, Bangkhen, Bangkok 9, Thailand. 119 pp. (A collection of 199 abstracts of water hyacinth articles up to 1970.)

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Part I

Using Herbivorous Animals

1 Grass Carp

The Chinese grass carp (*Ctenopharyngodon idella* Val.)* is a fast growing fish that feeds voraciously on many aquatic plants and grows to weigh as much as 32 kg. In several countries it is now being tested for aquatic weed control. It has proven to be an exceptionally effective control agent for submerged weeds in some parts of the United States. For example, in 1970, when grass carp were first introduced, an estimated 20,000 ha of public lakes contained submerged weeds in the state of Arkansas; in 1975, the state government determined that no infestations of problem magnitude remained in these waters.†

The grass carp converts aquatic weeds to valuable food. Already commercial fishermen in Arkansas are beginning to market the grass carp; it has gained instant acceptance there and is now recognized as a tasty commercial fish. Grass carp fillets are an excellent source of nutritious food. On a dry weight basis, they are approximately 80 percent crude protein (18 percent on a wet weight basis). The flesh is white, firm, flaky, and not oily.

The grass carp feeds primarily upon submerged plants but will also eat such small floating plants as duckweed. Overhanging terrestrial plants and bank grasses may be consumed when preferred plants are not available. The grass carp's teeth are located in its throat and, to feed, it must get the plant material to them. Plants that are eaten usually have stems and leaves small enough to fit lengthwise down the fish's throat; broad-leaved plants and plants extending above the water surface are not normally eaten. Submerged weeds consumed by the grass carp include hydrilla, water milfoil, chara, *Elodea canadensis*, *Potamogeton* spp., *Ceratophyllum demersum*, and most other submerged plants that are serious weeds.

Active feeding begins when water temperatures rise above 10°C with an optimum feeding temperature of near 26°C. Grass carp grow fast. Under optimum conditions they may attain an edible size (1 kg) in one year; thereafter, growth increases of 2–3 kg per year in temperate zones and up to

*Known in the United States and the USSR as the "white amur."
†Information supplied by W. M. Bailey. (See Research Contacts, at end of chapter.)

Grass carp feeding on aquatic weed. The fish can feed only on the ends of plants, as the teeth used to macerate the plant tissues are located in the throat. (Weed Research Organization)

4.5 kg per year in tropical regions can be attained. Weight increases up to 6 g per day have been measured for grass carp feeding on hydrilla in Florida.*

With this rapid growth, grass carp quickly consume stands of aquatic weeds. Small fish, less than 1.2 kg, may eat several times their body weight of plant material daily. Large fish, under favorable conditions, consume their body weight daily. The digestive tract is short, only 2-3 times the body length. Only about 65 percent of the plant material eaten is digested. The remainder passes through undigested and is excreted as dense pellets. In experimental ponds, 50 kg of fresh hydrilla was consumed for each kilogram of fish produced. In the absence of aquatic weeds, grass carp can be fed on terrestrial plants; in Malaysia it is common practice in the intensive culture of grass carp to feed them napier grass.

Weed control is rapidly achieved if more than 75 fish per hectare are present. Lower stocking rates reduce the rate of weed control, but result in larger, more valuable food fish. Quite apart from weed control, the grass carp can be cultured for food. Yields of 164 kg of fish per hectare in temperate

*In reviewing this chapter Lee Chan Lui (see Research Contacts) reported that "In Malacca it has been conclusively established that grass carp can grow from fingerlings (20 g) to 2-2.5 kg in 6 months. Once this size is reached the fish can grow approximately 1 kg per month for the next 6 months, i.e., the fish can reach a size of 8-8.5 kg in a year. It's without doubt one of the fastest (if not *the* fastest) growing fish in the world."

zones and 1,500 kg per hectare in tropical weed-infested waters have been obtained. This is usually done in polyculture in which several different fish species are grown together, each living off a different food in the pond. This is amply described in a recent book.*

Grass carp may be harvested from lakes or streams using gill nets, trammel nets, hoop nets, and seines. They are very agile and frequently leap over capture nets. They can also be caught with fish traps, hooks baited with vegetation, or the fish poison rotenone.

Limitations

When introduced into a new country, grass carp should be initially maintained in quarantine, and only released when known to be free of serious pest parasites and diseases. They should also be tested to determine any adverse effects they might have on native aquatic animal life. During the first few weeks after hatching, grass carp are not herbivorous. They eat zooplankton and other microscopic animals. It is not until the fry become fingerlings that they begin feeding on filamentous algae and small stems of tender plants. In some parts of the United States and other countries, such as New Zealand, it has been argued that the fry might eat the eggs or fry of native or sport fish, such as trout and bass, and reduce their populations. As of late 1975, however, there was little evidence that this occurs. Nonetheless, some governments have objected to the introduction of grass carp because they fear that it may spawn excessively and adversely affect recreational fishing for trout, bass, and other sport fish. Projects are now under way in Florida and in New Zealand to test for such adverse effects. Among researchers it is generally believed that the fears are unjustified.†

Research into grass carp genetics has recently led to methods for producing fish of the same sex. Although at the present time these are more expensive to produce than fish of mixed sexes, when introducing grass carp to new countries and waterways it is far safer to use them. Since no reproduction can occur, the fish will die out after one generation. This permits a trial introduction: if judged undesirable, the fish can be allowed to die out; if judged desirable, new stocks can be added.‡

In most waterways outside its native China the grass carp has failed to spawn naturally; however, it did spawn at least once after introduction into

*Bardach, et al. 1972. (See Selected Readings.)

†Some have reported that grass carp benefit other fish by removing weeds and recycling nutrients, but one paper from the Societ Union [Vinogradov and Zolotova. 1974. (See Selected Readings)] records that the grass carp seriously reduced fish production in fish farming, and enhanced the growth of undesirable plants.

‡Information supplied by J. Stanley. (See Research Contacts.)

The "Bois d'Arc," Arkansas, USA, was filled with submerged weeds (*Ceratophyllum demersum*) when grass carp were added in 1971. . . .

the Volga, Ili, Terek, Amu-Darya, and Kubon Rivers, as well as in the Kara Kum Canal in the Soviet Union, the Tone River in Japan and the Balsas River and Bodegas Lake system in Mexico. To date, these are the documented cases of the grass carp's reproducing naturally outside China. It therefore seems unlikely that the fish will spawn extensively and thereby become a pest.

Until recently, in fact, researchers reported difficulty in spawning the grass carp artificially. Now, however, the techniques have been developed and, at least in Arkansas where several million fry are produced each year, artificial spawning is routine.

Grass carp fingerlings must be carefully protected during rearing since they are vulnerable to predators and heavy losses can occur.

As a food fish, the grass carp has a disadvantage: Although it has fewer bones than many edible fish, it does have intramuscular bones and must be filleted skillfully.

Grass carp grow poorly on plants that are low in nutrients. They also eat little and their growth rate slows in waters where the oxygen content is low; nevertheless, they can *survive* highly eutrophic waters. Furthermore, they grow poorly when the water temperature drops below 10°C.

. . . Three years later the same lake is weed-free. (W. M. Bailey)

Once released into large waterways grass carp, because they eat aquatic vegetation, are not easy to catch by usual hook-and-line techniques.

Even when released into warm, placid waters where they are unlikely to reproduce, the upstream and downstream regions must also be considered, for if contiguous waters approximate the grass carp's natural habitat, the fish may be able to reproduce there.

Although water hyacinth, salvinia, and other problem weeds that float are sometimes eaten, they are not preferred, and the grass carp is not a satisfactory agent for controlling them. Neither is it good for controlling tall, hard, emergent aquatic weeds, such as cattails—though if the plants are deliberately cut off below the water line, the grass carp will kill them by eating all new shoots as they form.

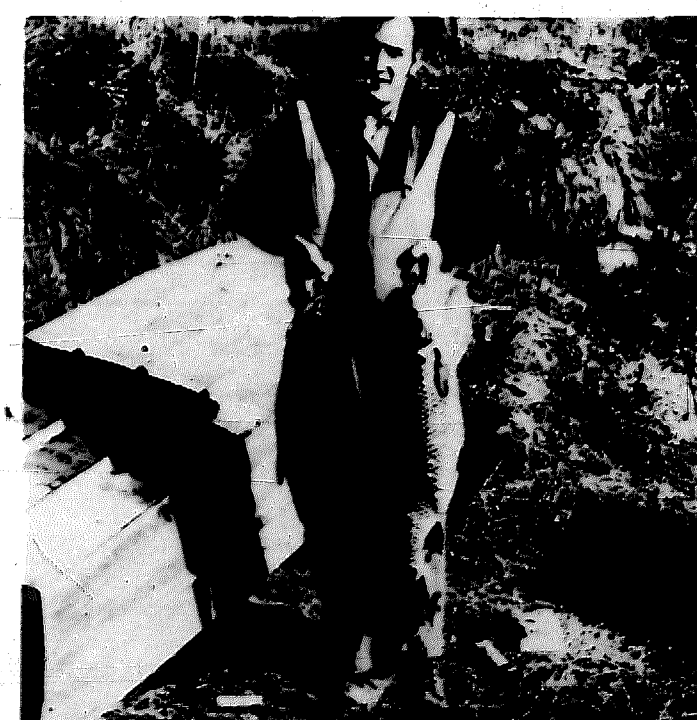
Research Needs

In the past decade the grass carp has been introduced into a score or more countries, and there is now much experience and knowledge to be shared among the researchers involved. Technical assistance agencies could greatly advance understanding of this herbivorous fish by sponsoring a conference at which the different experiences could be compared, lessons drawn, and the results published.

The main barrier to the wholesale release of the grass carp in some countries has been the uncertainty surrounding its possible effects on other aquatic animals. Increased research is needed to see if indeed there are any adverse effects.

The fact that natural reproduction is not common in tropical regions may indicate that the fish needs a distinct change in seasonal temperature to initiate spawning. Research on this and other factors that control grass carp reproduction is urgently needed. The information gained will provide administrators with the technical underpinnings necessary to judge the wisdom of introducing the fish to a new waterway.

The grass carp's practical yield potential is still unknown, and research is needed to determine stocking rates and disease and predator control, as well as the plant species and environments that raise its growth and productivity to a maximum.



Grass carp harvested by gill nets from Lake Greenlee, Arkansas, USA. (W. M. Bailey)

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Research Contacts

Grass carp have been introduced into a number of developing countries in recent years. For information readers should contact local government agencies with responsibility for inland waterways and fisheries.

Agricultural Research Center, 3205 S.W. 70 Avenue, Fort Lauderdale, Florida 33314, USA (D. L. Sutton)

Biological Faculty, Moscow State University, Moscow, USSR (G. V. Nikolsky)

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Central Inland Fisheries Research Sub-Station, Cuttack, Orissa, India

Commonwealth Institute of Biological Control, Indian Station, Bellary Road, Bangalore 560006, P. O. Box 603, India

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Directorate of Fisheries, Lahore, Pakistan

Fisheries Division, Arkansas Game and Fish Commission, P.O. Box 178, Lonoke, Arkansas 72086, USA (W. M. Bailey)

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Fisheries and Hydrobiological Research Section, P.O. Box 1756, Khartoum, Sudan (T. T. George)

Fisheries Research Station, Batu Berendom, Malacca, Malaysia (Lee Chan Lui)

Illinois Natural History Survey, Kinmundy, Illinois 62854, USA (D. H. Buck)

Indo-Pacific Fisheries Council, FAO Regional Office, Maliwan Mansion, Phra Atit Road, Bangkok, Thailand

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Polish Academy of Sciences, Experimental Fish Culture Station, Golysz 43-422 Chybie, Poland (J. Szumiec)

Regional Center for Tropical Biology (BIOTROP), P.O. Box 17, Bogor, Indonesia (S. Partoatmodjo, Director)

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Warmwater Fish Cultural Laboratories, Fish Farming Experimental Station, Stuttgart, Arkansas 72160, USA (M. Martin)

2 Other Herbivorous Fish

A number of herbivorous fish species in addition to the grass carp are being tested as aquatic weed control agents. A few that are notable for the quantity of vegetation they consume or remove are described in this chapter.

Fish that control aquatic weeds are classified as follows:

- *Grazers*, if, like the grass carp, they eat stems and foliage.
- *Mowers*, if they devour the lower portions of aquatic plants and thus cut them down.
- *Roilers and rooters*, if they stir the bottom sediments while foraging for food or preparing nests. These fish either roil up soil and fine debris, cutting off the light that the plants need for photosynthesis and growth, or they "root out" the plants and thus destroy them.
- *Algae feeders*, if they consume moss-like filamentous algae.
- *Plankton feeders*, if they filter floating, microscopic algae from the water.

Except in the Orient, the study of herbivorous fish is in its infancy. The work so far has focused on just one or two species, and there has never been a comprehensive analysis of a wide variety of plant-eating fish to determine their relative advantages and limitations. Nor has a thorough survey been made of all herbivorous fish to see if potential weed-control species have gone unnoticed. Such research is exciting and important, for not only can it help solve the aquatic weed problem, it can also help to make better use of the earth's limited resources. A food chain that grows fish on plant life rather than on higher organisms, for example, is a more efficient way of providing food. It is not impractical to visualize that the now-undesirable vegetation in ponds will be managed like pastures in the future, even to the extent of planting and culturing the plants solely for fish food.

Herbivorous fish have an important, but yet underexploited, role in fish farming using the polyculture technique. In this method pioneered centuries ago in China, fish species are selected for the different types of food they consume; then they are put in the same pond together. The combination makes use of each of the food types available in the pond and thus maximizes the amount of fish food grown. Polyculture systems often combine grass carp (see Chapter 1) with silver carp (see below), an algae feeder; common carp (see below), an omnivore; and a zooplankton feeder.

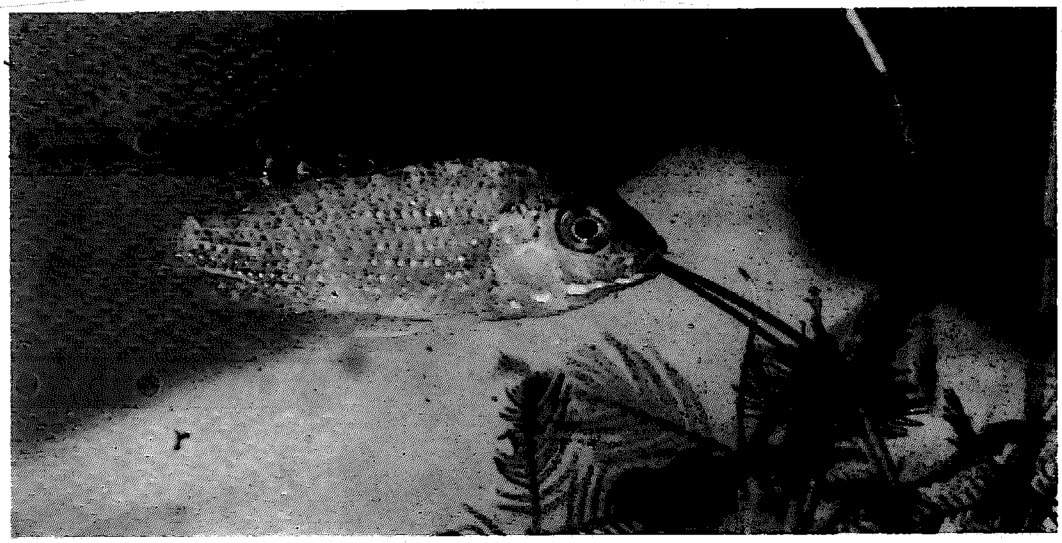
Tilapia

Tropical lowland fish common in Africa and the Middle East, tilapia have been important food sources for millennia. The fish Jesus fed to the multitude over 2,000 years ago are supposed to have been tilapia. Although occasionally omnivorous, tilapia are principally herbivores. Some prefer higher plants, some filamentous algae, some plankton, while others consume various aquatic fauna. Several species are voracious feeders and are used to control weeds.

Tilapia are prolific and hardy, and can be cultured in stagnant ditches and pits fatal to other useful fish. They are cheap and easy to breed, grow rapidly, and their flesh is much valued as food. With little help, African and Asian peasant farmers have quickly learned to culture them in small-scale subsistence and commercial enterprises. There are few comparable herbivores among the world's fish.

Tilapia are essentially tropical fish, but they can live under a wide variety of conditions. Many species are little researched and almost nothing is known of their potential for utilizing aquatic weeds. Some of them may give better results than the species that have been spread widely through the tropics. Because different species of tilapia will mate and produce hybrids, the fish may eventually be bred for desirable characteristics. Many tilapia consume the larvae of midges and mosquitoes, both of which spread disease to man, and they reduce the niches between plants that protect the larvae from other predators.

Tilapia have limitations, however; they breed so prolifically that a waterway becomes overpopulated; stunted fish, too small for eating, result. Techniques for keeping tilapia populations in balance are known but require skill to use successfully. Currently, the most effective method is to add a predatory fish to the waterway. This then preys on the young tilapia and, if edible, can be useful itself. Another population control technique is based on the tilapia's unusual genetics. Crosses between species surprisingly can produce hybrids of one sex only. At least three crosses using different species of tilapia have produced hybrids that are entirely of the male sex. These can, of course, be stocked without fear of reproducing. Much research remains to be done to test more crosses and the fecundity and feeding habits of the hybrids. Such genetic research promises to revolutionize the use of tilapia for weed control.



Young *Tilapia zillii* feeding on stem of water milfoil. It prefers aquatic plants, but will also consume filamentous algae. (R. R. Yeo)

Potential but as yet unexploited sites for tilapia rearing are weed-infested wastewater lagoons and other enriched ponds. Most tilapia tolerate such nutrient-rich waters and different species can graze the weeds, plankton, or filamentous algae that grow there.

Tilapia zillii

Primarily herbivorous, this species generally feeds on aquatic plants, but it will also consume midge and mosquito larvae. Native to the Middle East and Africa north of the equator, it has been found to be a satisfactory weed-control agent in irrigation canals in the United States. *Tilapia zillii* fingerlings are now reared in geothermal waters and stocked in weed-filled canals in the Imperial Valley of Southern California at the rate of 2,500 fish per hectare. Over half a million were stocked in 1975. They completely eliminated submerged weeds in the waters where they were placed.*

Many *Tilapia zillii* die in Southern California's cool winter; others become lethargic and easy prey for predacious fish. They must be restocked each year. In tropical areas where year-round temperatures exceed 22°C this is no problem. *Tilapia zillii* are edible and are farmed for food in East Africa.

Tilapia rendalli

Tilapia rendalli (often referred to incorrectly as *Tilapia melanopleura*) occurs naturally in rivers of eastern and southern Africa including the upper Zambezi,

*Information supplied by W. J. Hauser. (See Research Contacts.)

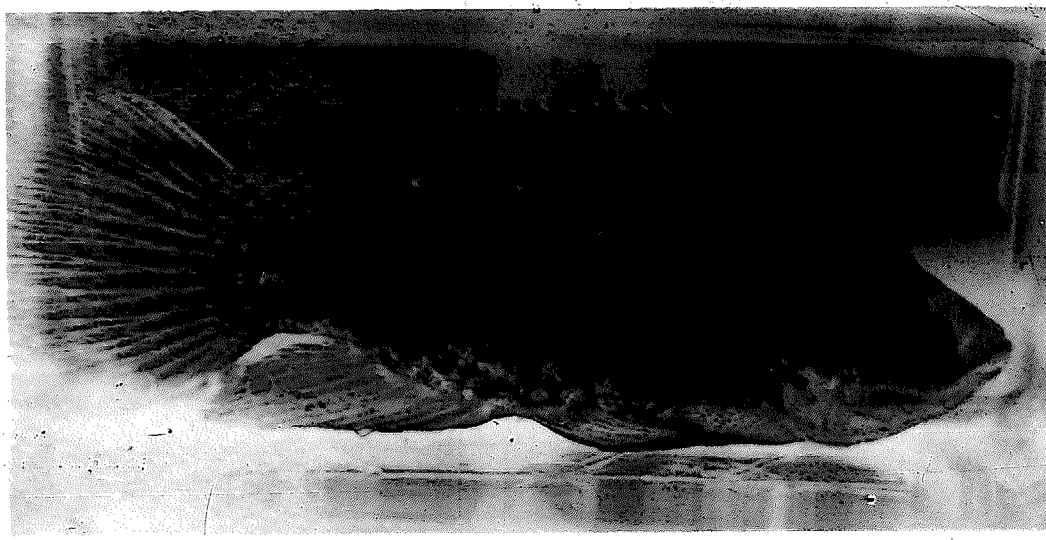
Tilapia rendalli (C. Philippy)

Limpopo, Congo (Zaire), and in Angola. The fish is now cultured commercially for food throughout Africa. It is a herbivore that prefers submerged aquatic plants, and, like the grass carp, is an efficient grazer.

Tilapia rendalli will consume an established stand of vegetation in one season if stocking rates of 2,500–5,000 young fish per hectare are used. A lesser number of fish are used to keep regrowth suppressed. These fish are prolific breeders, capable of reproducing when 2–4 months old and, if the water is warm, they spawn every 3–6 weeks after that. The large numbers of fish produced convert large masses of plant material into fish flesh. Indeed, they often become excessively stunted by lack of food and may never reach a size suitable for human consumption. However, if the population is controlled, *Tilapia rendalli* may reach 30 cm and weigh 0.7 kg.

Tilapia guineensis

This estuarine tilapia from West Africa (originally classified incorrectly as *Tilapia melanopleura*) is one of the few salt-tolerant fish that feed largely on plants (macrophytes). Although it is most at home in brackish waters (25–75 percent seawater) it can be found in the sea and can be kept in freshwater for considerable periods. Above 5 cm in length *Tilapia guineensis* feed predominantly on terrestrial vegetation washed into estuarine areas. This fish may be



Female Java tilapia (*Sarotherodon mossambicus*), which eats large quantities of filamentous algae. The flesh is edible. (R. R. Yeo)

a valuable and under-recognized species for estuarine and brackish-water culture.*

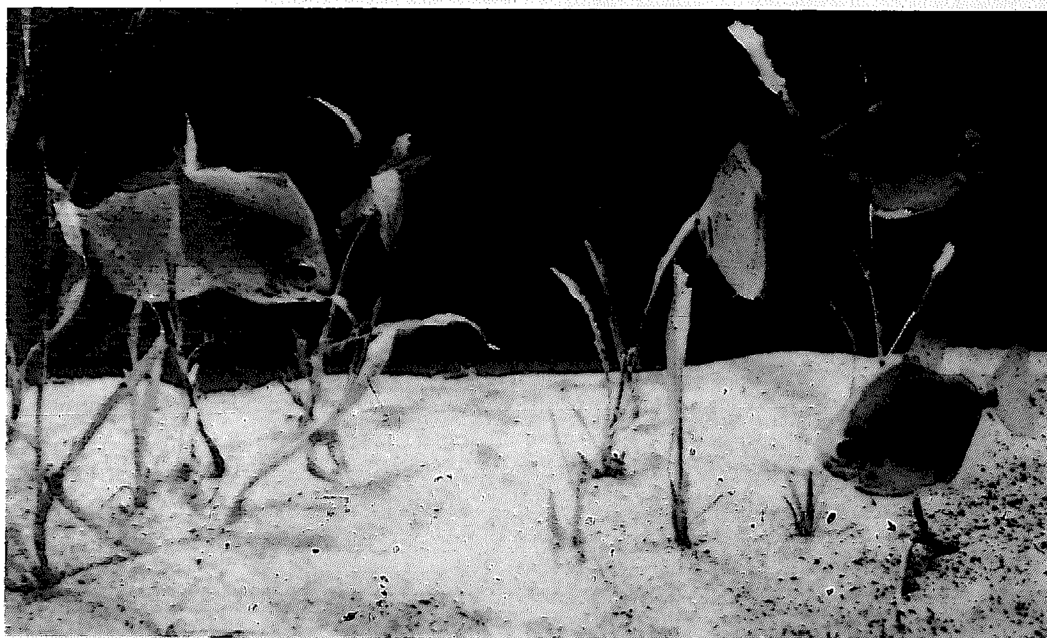
Sarotherodon mossambicus

This species (formerly called *Tilapia mossambicus*, and commonly known as "Mozambique tilapia" or "Java tilapia") consumes filamentous algae and plankton, a useful characteristic because filamentous algae (such as *Enteromorpha* spp.) provide a prime mosquito-breeding habitat by sheltering mosquito larvae from predators. The Java tilapia can be stocked with a larvae-eating fish (e.g., the mosquito fish *Gambusia affinis*) in an integrated algae-mosquito control program. It can also be stocked in rice fields (after the rice has emerged) to feed on the red alga (*Euglena sanguinea*) and other algae that rob rice plants of nutrients.

Sarotherodon mossambicus are edible and, in Puerto Rico, males have grown to weigh as much as 2.7 kg.†

In 1957 it was reported that on one 1,400-ha sugar plantation in Hawaii the costs to control aquatic weeds were reduced to virtually nothing by using *Sarotherodon mossambicus*. Seventy-five thousand fish, each 7–10 cm long, were released into the irrigation channels. Before they were released, algae and weeds were removed by using chemicals and, given this start, the fish

*Information supplied by I. Payne. (See Research Contacts.)
†Information supplied by R. R. Yeo. (See Research Contacts.)



Silver Dollar Fish. *Mylossoma argenteum* eat large quantities of aquatic plants (such as *Potamogeton* spp. shown). They often graze the stems close to the root zone, cutting off the bulk of the plant, which then decays and dies. (R. R. Yeo)

were able to suppress the regrowth. The initial cost was $3,000, compared with a previous $5,000 *annual* cost for control using herbicides. The annual cost for weed clearance in the subsequent years was quoted as $25.*

Sarotherodon niloticus

The Nile tilapia (formerly known as *Tilapia niloticus*) consumes large amounts of filamentous algae, such as *Pithophora* spp. Stocking rates of 2,500–5,000 per hectare in ponds will control this algae. They will consume some higher plants, but not enough to control them.

Silver Dollar Fish

The small, tropical, herbivorous, South American fish *Metynnis roosevelti* and *Mylossoma argenteum* (commonly referred to as "silver dollars") can control a variety of submerged aquatic weeds. They are aggressive eaters and, when traveling in schools, consume large quantities of submerged aquatic vegetation, including many pondweeds. Silver dollars are mowers; they frequently bite off the weeds at the base of the stem close to the roots. The mass of

*H. M. Hee. (See Research Contacts.)

loose vegetation floats to the surface; there, the silver dollars usually graze it later or leave it to accumulate along the shoreline where it decays. Dense growths of vegetation are rapidly removed from ponds when the fish are stocked at rates of 1,200–2,500 fish per hectare. Little is known of their potential yield or value as food, other than that they occur in large numbers and are sought after and relished by the people along the Amazon River. They grow to a length of 13 cm and are related to and resemble the piranha (*Serrasalmus* spp.); so much so that they are sometimes mistaken for this dread carnivore. Their bright silvery color and small scales enhance their attractiveness as food and as bait for other fish. Harvesting techniques are similar to those used to catch tilapia.

Silver dollars become active grazers in warm waters, 21–35°C. In temperate countries heated facilities are needed for over-wintering; temperatures less than 16°C are fatal.

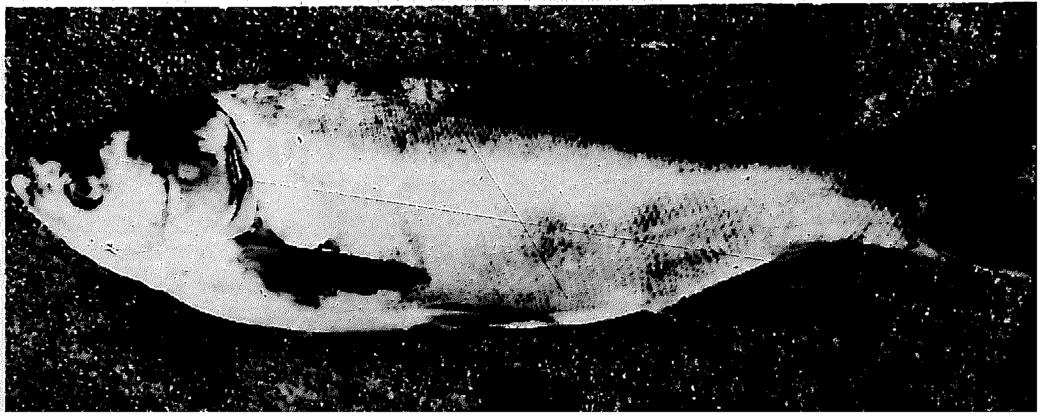
Considerable research is needed on silver dollars to identify the weeds they consume or shun; the techniques for spawning, culturing, and managing them; their value as food; and their sensitivity to adverse water quality.

Silver Carp

A silvery, shad-like minnow from China, the silver carp (*Hypophthalmichthys molitrix* Val.) is a short-bodied fish that consumes only microscopic algae. It has extremely fine-meshed gill rakers, which strain its planktonic food from the water. It will also eat such processed foods as bean meal, rice bran, and flour. A large, rapidly growing fish, silver carp can grow to weigh 15 kg.

This species is an important source of protein in the People's Republic of China and other Asian nations. As such, it is bred extensively for food. Several thousand fish per hectare can be grown in highly enriched ponds or lakes. The silver carp does not reproduce in lakes or ponds but may spawn in rivers that meet its specific requirements. It is easily spawned artificially using hormone injections.

Silver carp, a hardy fish that filters and consumes large quantities of microscopic algae from the water. (W. M. Bailey)



Silver carp can survive in eutrophic waters, and with an increasing number of eutrophic waterways worldwide, they have an important future. Because fish farmers often suffer great losses of fish stock caused by heavy algae blooms, the algae-eating capability of the silver carp is important to conventional aquaculture. The big head carp *Aristichthys nobilis* also displays these desirable characteristics. A similar plankton-eater *Megalobrama bramla* is used in place of the silver carp in South China and in Indochina; the sandkhol carp *Thynnichthys sandkhol* is another similar fish often cultured in Malaysia.

Miscellaneous

A few other weed-eating fish that appear to have potential for converting aquatic vegetation to useful fish flesh are described below.

Tawes

Not a high-quality food fish, the tawes (*Barbus gonionotus*) will eat some aquatic weeds (though it is not very effective at controlling them). It is used in Southeast Asia for controlling filamentous algae and for aquaculture.

Common Carp

The common carp (*Cyprinus carpio*), though an omnivore and primarily a scavenger, will feed on filamentous algae (including species of *Pithophora, Rhizoclonium*, and *Cladophora*), and, to a limited extent, on higher plants. These fish are roilers and uproot submerged weeds as they scavenge around in the bottom mud looking for insect larvae and other small animal life. Rooted weeds have been cleared by stocking at a rate of 130–250 common carp (15 cm long) per hectare. Only a little of the vegetation is eaten; the rest decomposes. Common carp are hardy, they tolerate wide differences in temperature and salinity, and they can be easily spawned and cultured. The Israeli or mirror strain, in particular, is a prized food in many parts of the world.

Tambaqui and Pirapitinga

Two fish, *Colossoma bidens* (tambaqui) and *Mylossoma bidens* (pirapitinga), widely distributed in the Amazon River Basin, are attracting attention in Brazil. They are thought to have great potential in pond culture. Both have much commercial value in the Amazon region and both are large [illegible] Tambaqui may attain lengths of 1 m and weigh 20 kg; pirapitinga grow to about half that size. At the Pentecoste Fish Culture Research Station in Ceará State, Brazil, tambaqui show a higher annual production than any other fish tested.

Both fish eat zooplankton and phytoplankton but they will also eat vegetation, particularly fruit. Pirapitinga readily feed on bananas, pieces of watermelon, guavas, cucumbers, fresh corn, beans, and bean shells. They are hardy fish, resistant to handling and seining, and if the dissolved oxygen drops to extremely low levels of below 1 ppm, they can survive by gulping air!

Spawning techniques and methods for rearing fingerlings remain to be worked out for both fish.

American Flagfish

The American flagfish *Jordanella floridae* is a small fish growing to 6 cm. Schools of these fish consume large quantities of filamentous algae and the soft parts of submerged plants. They tolerate low temperatures. Little is known of the potential of this fish for utilizing aquatic vegetation.

Goldfish

Some large strains of the common goldfish *Carassius auratus*, widely used as an aquarium pet, will eat vegetation. They will consume filamentous algae such as *Pithophora* spp. and can give good algae control when stocked at about 1,700 per hectare.

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A comprehensive bibliography of phytophagous fish is available from the Department of Fish Culture, Poland (see address below).

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3 Manatees

The manatee, or "sea cow," (*Trichechus* species) is indigenous to 40 tropical countries. A large, warm-blooded, air-breathing herbivore, it is a docile, retiring animal that has been suggested as a weed control agent for tropical nations of Central and South America, the Caribbean, and West and Central Africa.

But the manatee is threatened by extinction. It is one of the world's more endangered marine mammals—closer to extinction than many whale species. It cannot be removed from the wild and used for weed control; there are not enough individuals left.

Conservation and research are desperately needed to relieve the threat of extinction. If current populations can be preserved and restored, and if successful husbandry and artificial breeding can be achieved, the sea cow might have wide use in the tropics as an aquatic counterpart of beef cattle, a herbivore that grazes underwater pastures and produces nutritious meat and valuable hides for man.

Advantages

The manatee can live in both fresh or salt water and is often observed in estuaries. Strictly vegetarian, manatees prefer succulent submerged species but, if denied these and hungry enough, they will consume almost any type of water plant as well as many terrestrial grasses and leaves that come within reach. They may consume as much as a twentieth of their body weight each day. An adult manatee, exceeding half a ton and 3 m in length, possibly consumes 20 kg of wet vegetation each day.

Manatees readily adapt to confinement and, in Guyana, captive manatees have been keeping ornamental pools in Georgetown's Botanic Gardens clear of aquatic vegetation for almost a century. In addition, more than 50 manatees have been introduced into Guyana's irrigation canals, reservoirs, and drainage systems for weed control. In some they have been very effective. For

A report that describes this subject in more detail is available, *An International Centre for Manatee Research*. [For ordering information, see p. 173.]

Manatee nibbles aquatic grass, Florida, USA. These warm-blooded, tropical mammals eat large quantities of aquatic weeds and have been used in the Republic of Guyana and in Surinam to keep canals clear of weeds. Yet, at present, manatees are close to extinction and they cannot be used elsewhere until their conservation and husbandry is achieved. (N. D. Vietmeyer)

example, in the Georgetown Water and Sewerage Works, two manatees (each 2 m long) were introduced in 1952 to a canal (7 m wide and 1,500 m long) with a massive growth of submerged weeds. In only 17 weeks they had cleared it completely.* In the 24 years since then manatees have been used to keep this water (the city's municipal supply) weed-free.†

Manatees are a potential source of protein if a reliable program of captive propagation with effective enforcement of laws protecting wild populations can be developed. Alternatively, restoration and careful management of wild populations could produce a harvestable surplus for protein and other purposes, such as weed control.

Manatees may be more appropriate for controlling weeds in canals rather than lakes or rivers—a confined waterway allows better control and protection. Manatees may live as long as 50 years, and Guyana's experience shows that a few animals can maintain canals weed-free for decades. Though large, manatees tend to remain passive and immobile out of water and thus can be transported safely. They can survive in water that is fresh, brackish or saline, acid or alkaline, muddy or clear.

*Allsopp. 1960. (See Selected Readings.)
†National Science Research Council of Guyana. 1974. (See Selected Readings.)

Limitations

The number of manatees in some countries may be adequate for the animal to be used in small-scale local weed control programs, but it is on the international and U.S. lists of endangered species and protected in most countries where it exists. Nowhere are there populations large enough to support an export trade to nations that would like to introduce the animal.

Hunting manatees as a source of meat is wasteful, undesirable, and irresponsible. The few wild populations known to exist are inadequate to support any significant harvest levels for this purpose; artificial propagation has not yet been achieved; and any inadvertent stimulation of a commercial market for manatee meat would drain the already depleted wild stocks disastrously.

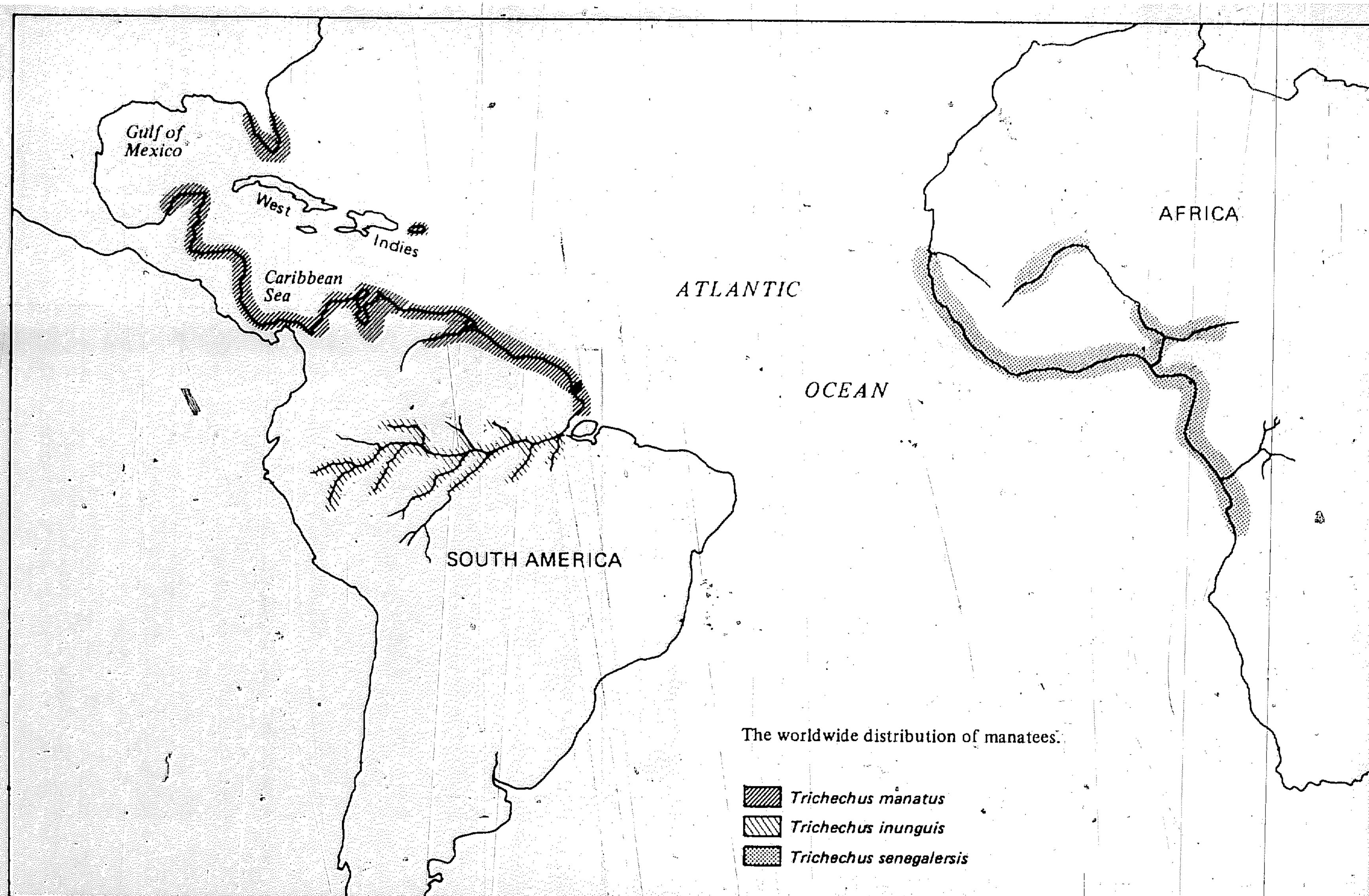
Manatees rarely breed in captivity or semi-captivity. The reasons are unknown, but are perhaps related to a nutritional deficiency, confinement-induced stress, or inadequate space in which to move about. In addition, they evidently have a slow reproductive rate and deductive speculations suggest that the gestation period may be about 13 months, while cow manatees probably breed no more than every 2 years. In most areas manatees are so

In 1965, a drainage canal in eastern Florida was choked with submerged weeds and woody emergent reeds and cattails. To this 0.8-km stretch of canal were added 5 full-grown manatees. . . .

. . . Three weeks later the submerged weeds were entirely consumed and the emergent plants had been cleared to the shoreline. (P. L. Sguros) rarely seen that to catch them alive is difficult, expensive, and damaging to the wild populations.

Protecting the manatee may also prove unexpectedly difficult. In narrow canals, manatees may be vulnerable, since in confined areas they can be easily hunted owing to their regular breathing and feeding habits. They drown if trapped in nets and culverts, unable to surface to breathe air. Water temperature is important if the animals are removed from their tropical environment: Below 18°C manatees may die from complications, including pneumonia. This restricts their use to truly tropical waters. Animals introduced into confined waterways in semi-tropical areas, such as Florida and upland Mexico, were unable to escape lower water temperatures during cold weather and died, presumably due to the cold. Manatees require waterways at least 2 m deep (though they will enter shallower sections to feed). In navigable waterways they can be damaged or injured by barges or fatally wounded by boat propellers. Because of their size they may overturn fast-moving boats or water skiers.

If used for weed clearance, care must be taken to balance the number of manatees with the growth of vegetation that the canal can sustain. In most cases, a weed infestation must be reduced by some other method and then just enough manatees added to keep the regrowth in check.



The worldwide distribution of manatees.

In open water, the manatee may not be able to control all aquatic weed species by itself. It may have to be used in conjunction with other methods to remove any massive growths of vegetation.

Research Needs

Too little is known about manatee reproduction. Comprehensive physiological or endocrinological and behavioral studies are needed to understand and accelerate the animal's breeding. These studies are needed before any captive breeding programs can supply animals for weed control projects. Other basic biological information is needed as well. For example, we must learn the nutritional and environmental requirements of the animal. To ensure reproduction and normal health of captive animals it is necessary to understand better the process of digestion, osmo-regulation, respiration, and the blood system. Furthermore, we must identify and control diseases, predators, and parasites that affect manatees. These data are needed for captive manatees but will also be invaluable for the preservation and restoration of the remaining wild populations.

Research is also needed on the status of the populations in the 40 countries where the animal exists, and protective legislation, sanctuaries, and enforcement of existing laws may be needed. Many administrators need to be made aware of the potential value of manatees. As in Guyana, a manatee pond in a public place may be used to educate the public about the ecological significance and national importance of this gentle, friendly creature.

The ecological impact of manatees on their environment, especially in restricted areas, needs site-specific studies to assist management decisions particularly for areas in which the waterways are needed for transportation, recreation, fishing, water supply, etc.

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4 Crayfish

A gourmet's delight, lobsters command extraordinary prices and are the basis for large commercial fisheries and a flourishing international trade. Lobsters live in the sea, but in most countries freshwater counterparts are common in streams and lakes. Most of these belong to the genera *Orconectes, Procambarus*, and *Cambarus* and are known as "crayfish," "crawfish," "freshwater lobster," etc. These animals are usually about 10–18 cm long but, like lobster, have large and edible tail muscles. Boiled in salt water, they are a delicacy. Frozen crayfish tails are becoming a valuable export from many countries including Turkey and the United States.

Although held in esteem and produced commercially in some European countries and a few areas of the United States, crayfish are a greatly underexploited food source. Only a few tribes in New Guinea use them extensively; yet, for those tribes, they are a major protein source.*

Crayfish are native to all continents except Africa and Antarctica. Over 300 species are known. A few are exclusively herbivorous. They appear promising for aquatic weed control and utilization. *Orconectes causeyi*, a species native to the western United States, has been used experimentally for weed control and was effective against pondweeds (*Potamogeton* spp.).† *Orconectes nais* has been shown to control aquatic weeds in Kansas. Beyond that, little is known about the herbivorous species.

Most crayfish are omnivorous scavengers but readily become vegetarians if necessary. Some of the plants they eat can be noxious aquatic weeds. In some ponds in the United States certain weeds are now deliberately planted for crayfish food. In general, crayfish should be thought of more in terms of an available crop associated with aquatic weeds, not as a weed-control agent. Crayfish live in shallow waterways, and some are well-adapted to warm tropical conditions. They tolerate wide ranges of soil type and water temperature and quality. Only a few species are well-known and the following discussion is largely based on *Procambarus clarkii*, the red crayfish, an omnivore that is widely farmed in Louisiana.

The young grow rapidly and mature in 6 months, reaching a weight of 40-45 g. To grow the large specimens that bring the highest prices may take

*Bardach et al. 1972. (See Selected Readings.)
†Dean. 1969. (See Selected Readings.)

The red crayfish (*Procambarus clarkii*) that is farmed in beds of aquatic weeds in Louisiana and Arkansas, USA. Although these omnivores do not prefer plants, they will consume all vegetation available to them–including water hyacinth–if there is nothing better to eat (a situation that commonly occurs when their populations are very dense). (Cities Service Oil Company)

8–14 months, however. In California and Louisiana, they are grown in flooded rice fields as an incidental crop. The crayfish live mainly on the aquatic weeds that grow among the rice.* When the fields are drained for harvesting the rice, crayfish congregate by the thousands in the depressions that are the last to dry and can be scooped up by the bucketful.

Some growers cultivate crayfish intensively in rice fields, and harvests of more than half a ton per hectare have been achieved. Once established, a crayfish population can be self-sustaining if some egg-carrying females are returned to the waterway at each year's harvest.

The red crayfish is the species that has been most intensively cultured, but other species show promise for aquaculture including *Orconectes limosus rafinesque* (for muddy and polluted waters) and the disease-resistant California crayfish *Pacifastacus leniusculus.*

Limitations

The adverse effects crayfish may have on other aquatic life are little known. However, omnivorous species will feed on fish eggs and fish fry. Thus, introducing omnivorous crayfish to a new area may possibly harm traditional fisheries. *Local crayfish species should always be the first tested, both as a wild crop and in managed farming.*

If nonindigenous crayfish are introduced, their potential impact must be thoroughly studied under strict security before they are released into the aquatic environment.

Imported crayfish have become a problem in Japan and in Hawaii where some rice and taro paddy dikes have been weakened by their burrowing. This behavior is typical of *Procambarus* and can be avoided by using other species. Also the adult crayfish eat tender shoots of newly germinated rice.

Crayfish should not be introduced into regions of West and Central Africa where the river blindness disease is prevalent. The *Simulium* fly that transmits the disease sometimes attaches its larvae to the backs of river crabs; it is possible that crayfish would be similarly used.

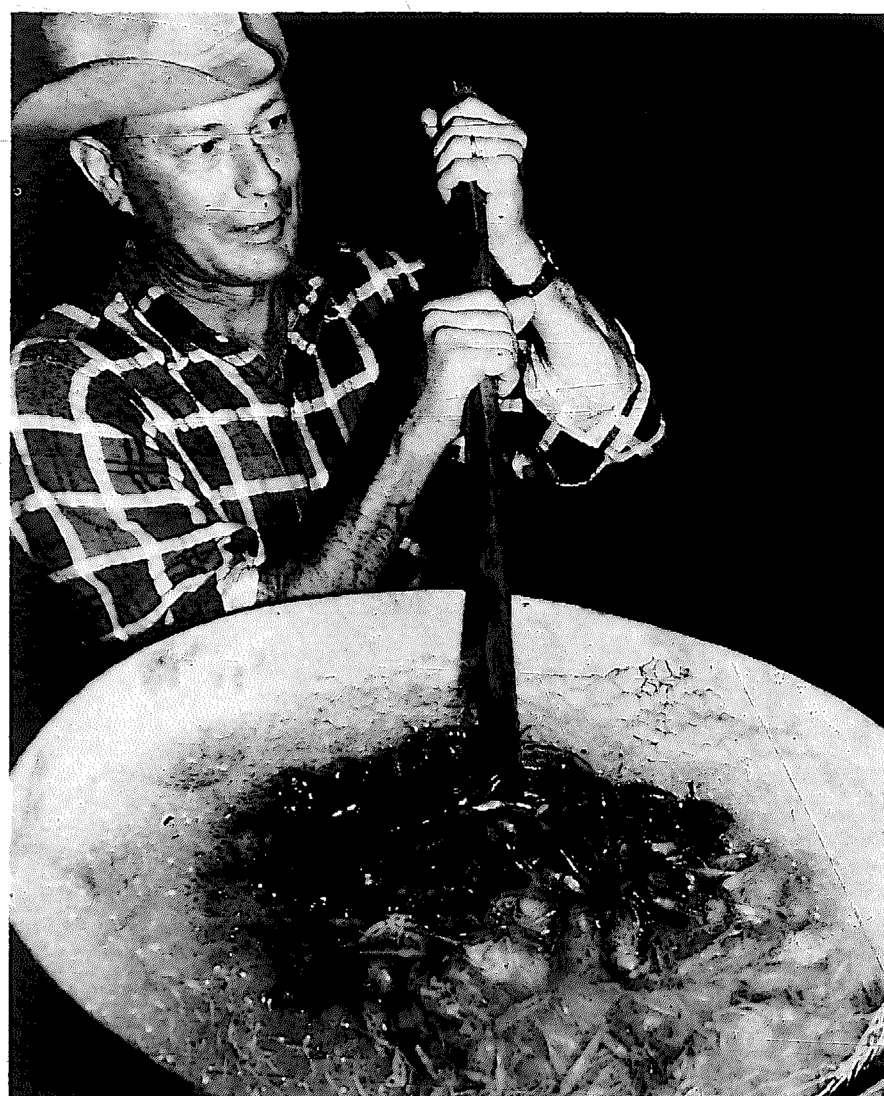
Annual draining is essential in water systems that become infested with predator fish. Unless these fish are removed, they will rapidly consume the young crayfish.

Crayfish avoid tough, woody, aquatic weeds and find many floating aquatic weeds inaccessible. They do not control or utilize such weeds as cattails and water hyacinth.

*The crayfish are too small to eat the crop when the paddies are flooded and the rice planted, and by the time the crayfish mature the rice plants are too fibrous and tall to be eaten.

On a crayfish farm workmen set out traps among the weeds. Crayfish crawl inside the baited traps, which are periodically emptied. Some fast-growing aquatic weeds, preferred by the crayfish (e.g., alligator weed *Alternanthera philoxeroides* and water primrose) can withstand much grazing and are deliberately planted as crayfish forage. (Cities Service Oil Company)

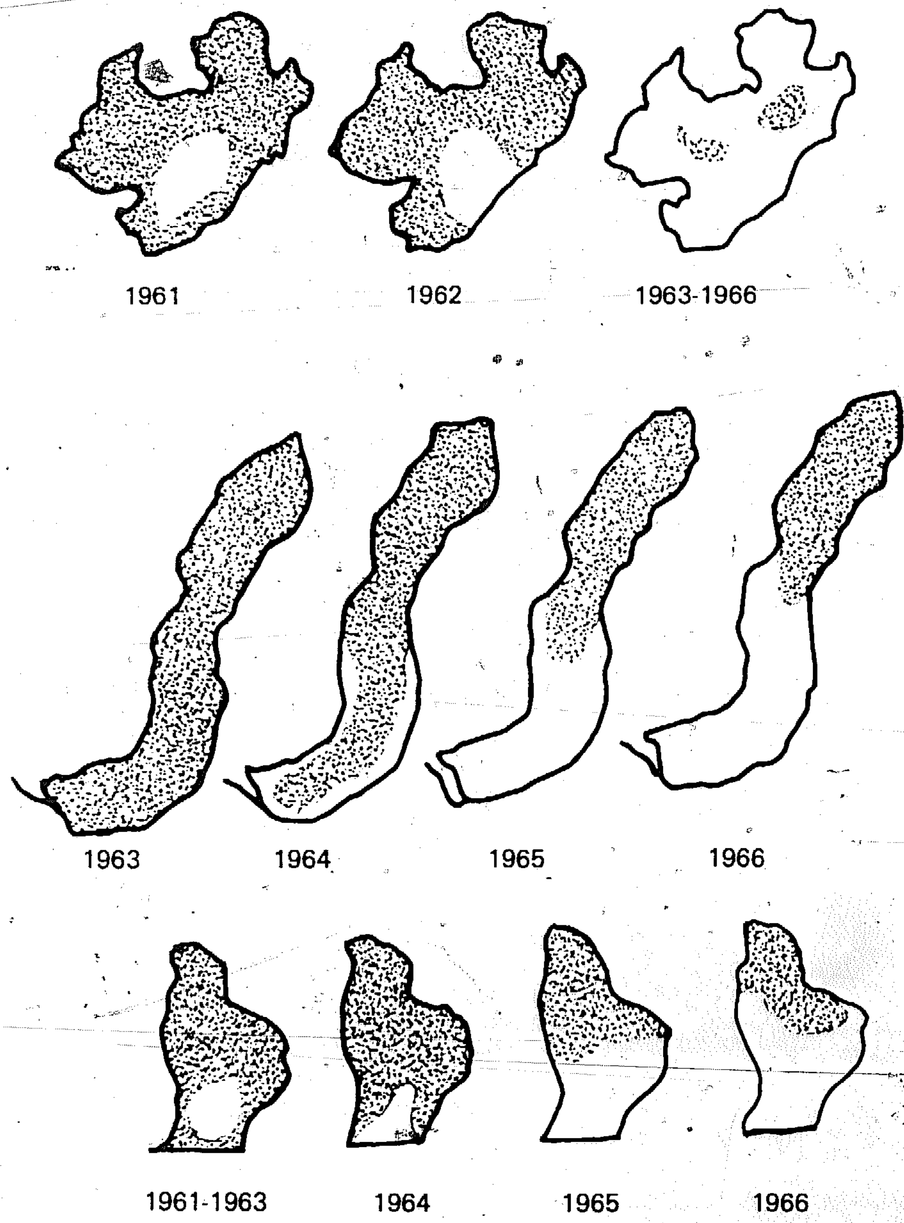
A serious complication in crayfish culture is the crayfish plague, *Aphanomyces astaci*, a fungus that is lethal to all species, except those from North America. Recently *Pacifastacus leniusculus* was introduced to northern Europe from California and is rejuvenating the former crayfish industry, which was devastated when native species succumbed to the plague. Actually, North American crayfish carry the plague but, for reasons yet unknown, it doesn't quite penetrate their carapaces. *Because the fungus they carry will decimate native species, North American crayfish must not be introduced to new regions*. Pollution is another threat. Crayfish are easily killed by synthetic chemical pollutants (chlorinated pesticides, industrial wastes, insecticides), which may enter the waterway upstream without the knowledge of the culturist. Crayfish are also relished by carnivorous fish, birds, snakes, turtles, etc. Protection is sometimes needed; the simplest technique is to provide a few dense stands of aquatic vegetation within which the crayfish can find shelter. Somes species may need a rocky bottom for shelter and spawning.



These freshwater relatives of shrimps and lobsters are a traditional food in France and Baltic countries. When boiled, they turn lobster-red and as a gourmet's delicacy rival their marine counterparts. (Ray Utt, Cities Service Oil Company)

Research Needs

Indigenous crayfish species that appear suitable for crayfish farming exist in most countries, except in Africa. These should be studied first and local biologists encouraged in this research. One particularly promising species is



Sketches of three shallow lakes in New Mexico, USA. The shading shows the extent of submerged aquatic weeds (species of *Potamageton, Myriophyllum, Elodea, Ceratophyllum*, etc.). The decrease in weeds was caused mainly by the native crayfish (*Orconectes causeyi*); neighboring lakes that lacked the crayfish remained weed-filled. Many of the weeds were cut off close to the soil; the leaves and stems floated away and decomposed. (Reproduced from Dean. 1969. See Selected Readings)

Astacopsis gouldi, a giant crayfish from the state of Tasmania in Australia that reaches 40 cm long and weighs about 3.5 kg. Another giant, *Astacus madagascariensis*, is found in the rivers of Madagascar and may prove even more suitable for tropical countries. A worldwide search for edible-size *herbivorous* crayfish is needed. Among the species, some are likely to prove good food and valuable aquatic weed control agents.

The food habits of crayfish, including their acceptance of various aquatic plants; practical techniques for rearing and harvesting crayfish; and the effectiveness of crayfish in removing vegetation under different aquatic situations—such as rice and taro paddies, ponds, canals, or reservoirs—all need thorough review and analysis.

Much of the crayfish is not eaten because most of the body is discarded; the carcass is high in calcium and nitrogen, both valuable fertilizer ingredients. Research is needed to determine the usefulness of the carcass in crop production and in animal feed.

In some locations crayfish are harvested from rice paddies as a supplemental food crop and are considered beneficial, while in others they are considered pests of rice paddies. Studies are needed to determine the effects crayfish may have on rice production. Without such studies there is potentially great danger in introducing *Procambarus clarkii* to Asian and South American rice-growing areas.

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5 Ducks, Geese, and Swans

Ducks, geese, swans, and other waterfowl forage on vegetation, controlling weeds on the banks of waterways and often clearing aquatic weeds and algae from small lakes, ponds, and canals. These animals have not been considered aquatic weed control agents. However, in Hawaii, 65 Chinese White goslings were placed in a 1-ha pond, completely covered with dense paragrass (*Brachiaria mutica*) and cattail (*Typha* spp.) that annually grew 1.8 m above the water. Despite the failure of mechanical and chemical controls to manage the weeds for several previous years, the geese cleared them out in 2½ years.*

Ducks and geese are small, easily managed grazing animals, well-suited to aquatic areas and wet marshy land. They produce nutritious eggs and highly prized meat. Completely at home in shallow, productive waterways, they are potentially immediately applicable to aquatic weed control in developing countries.

With their waterproof feathering, ducks and geese are well-adapted to high rainfall regions, and ducks in particular are an excellent fowl for hot, humid climates. Both animals readily adapt to captivity and can be raised in small-farm culture. To raise ducks or geese as opposed to raising larger animals requires little investment. They are readily available worldwide, and their nutritive and management needs are well-known. They are excellent foragers and may find all their own food or need only a minimum of supplements. In the right areas they can be raised by farmers to provide an additional income with little extra work.

Domesticated ducks are already raised throughout the tropics, notably in Asia, especially in aquatic weed-prone, riverine areas, but their effect on the weed problem is seldom considered. Yet 5-8 Muscovy ducks per hectare will control duckweed and some other aquatic plants. Coots (*Fulica* spp.) have controlled water hyacinth growing on sewage lagoons in the United States. In South Africa, as well, they are reported to eat the plant.

Geese are raised for their meat, which finds a ready market. Goose-farming is particularly important in Central Europe. For tropical developing countries, however, two breeds are known that could be more widely used: Chinese geese (White and Brown varieties), which are large birds (ganders can weigh

*Ross. 1971. (See Selected Readings.)

over 5 kg) that are already raised in Southeast Asia; and Egyptian geese, which are about 1 kg lighter but are hardy birds and active foragers.

Geese provide a farmer not only with protein but also with large amounts of fat and goosedown. Although sometimes messy, they cause little trouble and require little expense for they range freely without restriction, feeding themselves and returning of their own accord. However, in some areas, fences or a caretaker may be needed. Though they cannot digest cellulose, they are almost entirely grazers and eat both terrestrial and aquatic weeds. They also grub for underwater roots, which is important because few other animals uproot aquatic plants.

The use of swans to control aquatic weeds is rare. Yet, in 1967, 100 mute swans were added to Nissia Lake near Agras in northern Greece. The lake was being used to produce hydroelectricity, but the turbine inlets were clogged with aquatic vegetation. The swans (mostly unpaired singles) were first placed near the inlet area; they cleared it within a few weeks. They were then distributed about the lake.

The principal types of vegetation in the lake were reeds, *Potamogeton* spp., and chara (a submergent alga). The swans ate the young shoots and pulled the plants up to eat the tender roots. The chara was too deep for the swans to eat, so 60 pair of diving ducks (*Netta rufina*) were obtained to attack this problem.

Nevertheless, in the main body of the 900-ha lake the swans were less successful: Weed growth, bolstered by municipal wastewater, proved too

At a government training farm operated by teenagers near Port Moresby, Papua New Guinea, ducks are raised on duckweed and algae. These weeds grow on a small pond fertilized by sludge from a pig-manure methane generator (see Chapter 12). (N. D. Vietmeyer) great for them to have any appreciable effect. By 1976 the swan production had multiplied to perhaps 400 birds but was still inadequate to noticeably reduce the dense weed infestation.

Each winter the swans and ducks attract to the lake thousands of migrating waterfowl, including large numbers of coots, which also help control the weeds. But they all leave before summer when the weed problems are most severe.

The management of the swans is relatively simple: One wing is clipped to prevent them from flying away. The large lake provides plenty of vegetation, and no feed is given (in fact, they will not forage if they are fed). An advantage of swans over the other waterfowl was that they apparently needed no grain to supplement their diet of weeds.

Mute swans mature at about 5–7 kg and, while not commonly used for food in Europe—because of a reluctance to kill them—their flesh is as tasty as that of other waterfowl. In addition, they have a fine down, 2.5–5 cm, which can be woven into cloth.

While other swans might also be used for control of aquatic weeds, mute swans are the easiest to breed, producing about six young per year per pair. However, their initial cost is high (the equivalent of about US$150 per pair in Central Europe).

It seems most likely that waterfowl can control aquatic weeds noticeably only in small bodies of water such as farm ponds; in a larger waterway the number of birds needed to "solve the weed problem" makes their use impractical. Nonetheless, even here waterfowl could be used to supplement other weed control efforts such as the use of herbivorous fish or mechanical harvesting.

The birds can clear submersed weeds only in waters shallow enough for them to graze the plant back severely so that its growth is retarded. In deeper waters their grazing will have little effect on weed growth.

Probably geese are best used to control grasslike aquatic weeds. They may be ineffective on the broad-leaved types.

Limitations

Ducks, geese, and swans may need a diet supplement (e.g., grain) if they graze certain aquatic weeds exclusively. The farmer must strike a balance: Too little supplement may cause the birds to die of malnutrition; too much, and they will not eat the weeds.

These birds can defend themselves well, but ducks in particular require the added protection of a fence. They may require shade in hot countries, for they do not adapt well to hot arid conditions.

In its rice paddies, the Tahsia Commune, west of Canton in southern China, uses 220,000 ducks to eat and control insects, weeds, and the snails that transmit schistosomiasis, a dreaded parasitic disease. The ducks eat the succulent weed seedlings but shun the rice plants. They reduce weeds in the paddy by half, so that the rest can be removed by hand; no herbicides are necessary. After the ducks weigh 1 kg or so, they are marketed. This method allows the commune to greatly reduce its use of pesticides, and over 600 people are employed to herd the ducks through the paddies and to pen and feed them at night. (H. Beemer)

The trees show the boundary of this 100-m wide pond near Waialee on the Island of Oahu, Hawaii. It was a source of irrigation water until taken over by emergent aquatic weeds. Conventional weed control proved costly and unsuccessful; however, 5-week-old goslings were added early in 1966 when this photograph was taken. . . .
. . . Two years later the pond was clear. Even the foreground bank grasses had been cleared, though shrubby weeds were shunned. The geese themselves are an attractive addition. (E. Ross)

As both ducks and geese select out the most palatable plants in a given waterway, the remainder may have to be removed manually, mechanically, or by some other means. Geese, for example, prefer the young, tender shoots so an effective program may include an initial cutting or harvest. After that, the geese could be employed to control the new growth.

If not carefully managed, ducks and geese can become pests for some crops (especially grains) neighboring their waterway. Where sanitation is poor, salmonellosis sometimes decimates ducks, geese, and swans, and this disease can be transmitted, in their meat and eggs, to humans.

Research Needs

Using waterfowl to weed waterways is a novel concept. In order to develop it further, aquatic weed researchers should enlist the collaboration of professionals that have experience with waterfowl: local farmers as well as poultry

Mute swans have been used to control submerged weeds. In 1967 100 swans were stocked in a weed-filled lake near Agras, Greece. The population is now established and increasing. The swans do not control cattail. (S. Ehrlich)

and botanical scientists at local universities, and government research organizations. With such collaboration, some of the following areas of the concept may be illuminated:

- Which of the more important aquatic weeds are consumed? In what quantity?
- What level of diet supplementation is needed?
- What local ingredients can be used to make up a diet?
- What stocking levels are needed to control different aquatic weed species?
- What are the most appropriate species of waterfowl to use for clearing the different weeds?

In general, management systems must be developed for handling the different breeds or species of ducks and geese to ensure successful weeding. In addition to supplemental feeding, fencing and wing-clipping need to be studied. The need for partial clearing to provide access to the pond and the management of birds in brackish water also require study. When sufficient knowledge has been collected, it is possible that commercial techniques can be developed for raising ducks and geese on aquatic weeds. If so, it seems likely that research could identify breeds that feed on many of the problem weeds in aquatic habitats in developing countries.

The mute swan seems to withstand hot, as well as freezing, climates and should do well in tropical areas, but this needs more testing. Studies to increase egg production are needed, and studies on the use of artificial incubation may be useful.

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Many universities have a department of animal or poultry science that should know about the culture and management of these birds.

6 Other Herbivorous Animals

Though some herbivores may eat only portions of an aquatic plant—the leaves of water hyacinth, for example—in doing so, they reduce the fecundity of the plant and open its tissues to pathogens and parasitic infections. This chapter identifies some terrestrial herbivorous animals that can use aquatic plants for food. The animals are not in themselves effective weed control agents, but they contribute a measure of weed control by grazing on aquatic plants.

Water Buffalo

The water buffalo *Bubalis bubalis* is found throughout the Asian tropics and in more than 30 countries in the Mediterranean basin, South America, and the Caribbean. It swims well and is perfectly at home in tropical swamps. It is a robust animal and is more resistant to water-induced diseases, such as foot rot, than cattle. Also unlike cattle, water buffalo can feed under water on submerged aquatic weeds. During floods in Brazil's Amazon region, they have been known to dive 2 m deep to feed on the vegetation.

The friendly water buffalo is a good domestic animal for small farmers in developing countries. It provides milk, meat, hides, and work power, and the techniques for managing it are well established.

Although preferring terrestrial grasses, the water buffalo will graze aquatic vegetation. Initial observations in Florida have revealed that free-ranging water buffalo consume the shoots of cattail, leaves of willow trees (*Salix* spp.), and water hyacinth leaves. Little is known about their nutritional requirements, but the animal appears to grow on poor-quality, nutrient-deficient vegetation such as is often found in aquatic or swampy areas. In Florida they have consumed Cogon grass (*Imperata cylindrica*), a tall, coarse tropical grass with razor-sharp edges.

Feeding harvested aquatic weeds to water buffalo is a promising technique. In experiments, confined water buffalo have readily eaten ensiled water hyacinth plants (see Chapter 10). Before aquatic plants can be used in buffalo diets on a large scale, we must learn more about the nutrient content of individual species of aquatic plants and the nutrients needed as supplements.

Cattle eat semi-aquatic bank grasses and commonly wade into waterways to crop the leaves of water hyacinth and other emergent and floating aquatic weeds. (B. D. Perkins)

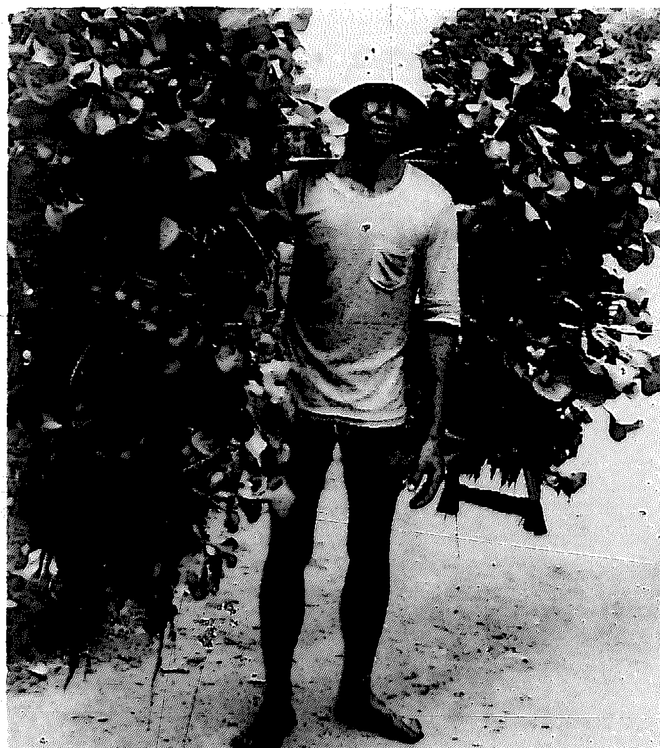
A water buffalo feeding on coarse semi-aquatic plants in a swampy area near Bangkok, Thailand. The buffalo is now gaining new esteem worldwide because of its ability to live in such wet conditions and to grow well on vegetation that is low in nutrients. Water buffalo may consume the water hyacinth directly, especially the flowers and young leaves. However, because of the plant's high water content, the amount consumed is not substantial. (N. D. Vietmeyer)

Capybara

Capybara are large, brown, tailless, semi-aquatic rodents that live in tropical Central and South America. The South American capybara *Hydrochoerus hydrochoeris* grows to be the size of a small pig, i.e., up to 60 kg in weight and 1.25 m in length. The Panama capybara *Hydrochoerus isthmius* grows to about half that size. They are also known as *chiguire* in Colombia and Venezuela and *carpincho* in Argentina and Uruguay. Capybara swim and dive readily and are fully at home in the water. They live along river and lake banks, in freshwater marshy areas, and are occasionally found on islands in river mouths, where the water is saline. Grasses and many aquatic or semi-aquatic plants make up the bulk of their vegetarian diet. During a drought they will feed on weeds, such as water hyacinth.

Capybara are readily tamed and may be worth domesticating. Research into capybara husbandry and management is now under way in Venezuela and Colombia. Each male mates with 2 or 3 females, in many cases producing 5-8 young per year. When confined, they may well be able to utilize aquatic weeds as part of their diet. This area of research should be encouraged.

A bicycle rickshaw load of water hyacinth, collected for cattle feed in Patna, India. During dry seasons in Bangladesh and West Bengal, water hyacinth is hand-harvested and fed directly to cattle, sheep and goats; they grow poorly on it, but it is the only green vegetation available. (Weed Research Organization)



Water hyacinth growing nearby a pig farming area will be harvested for pig feed. One animal may consume about 1.5–2 kg of fresh plants per day. Sometimes *Salvinia molesta* and *Hydrilla verticillata* are also harvested for pig feed. (M. Soerjani)

In Indonesia, water hyacinth is harvested for pig food. (M. Soerjani)

Sheep grazing the verdant marshes of the Danube Delta in Romania. (A. A. de la Cruz)

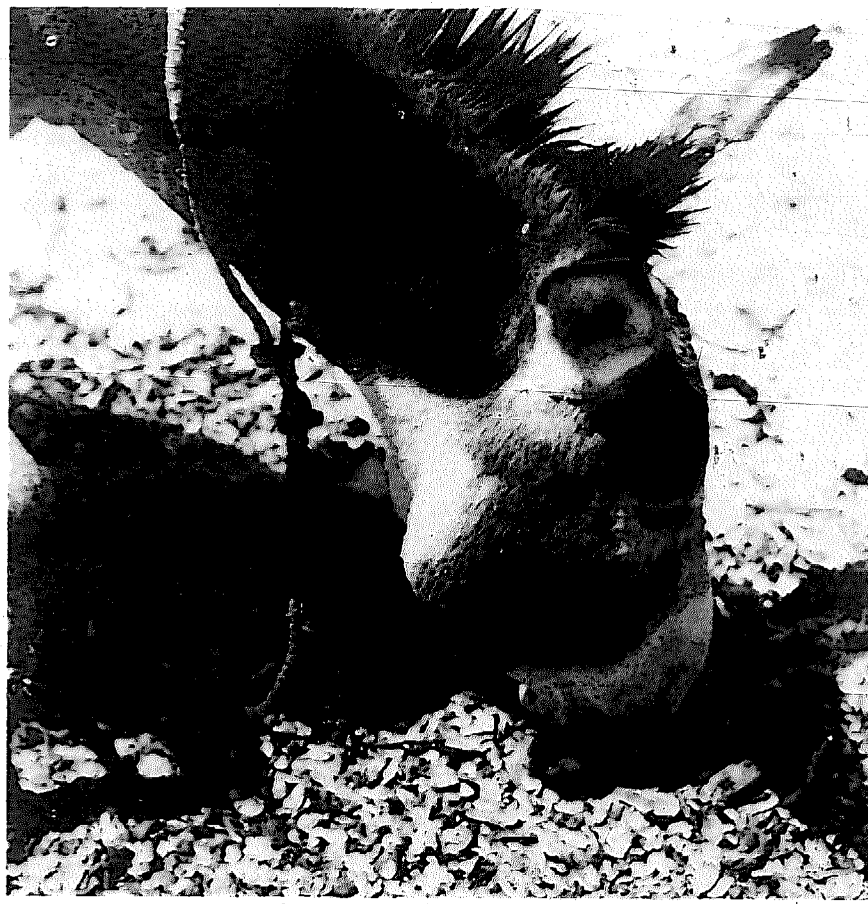
Capybara flesh is edible, but is not considered a delicacy. It has an unusual flavor; however, natives of South America eat it regularly. The curiously patterned capybara hide is valuable and is often used in South America for making soft, pliable gloves and purses.

Capybara should not be introduced into areas outside their native habitats. They can become pests and will invade crops such as maize, rice, cassava (manioc), melons, and sugarcane.

Nutria

Another amphibious South American rodent that lives in and around freshwater streams and ponds is the nutria (*Mycocaster coypus* Mol.), also called *coypu*. The nutria feeds mainly on aquatic plants including some problem weeds.

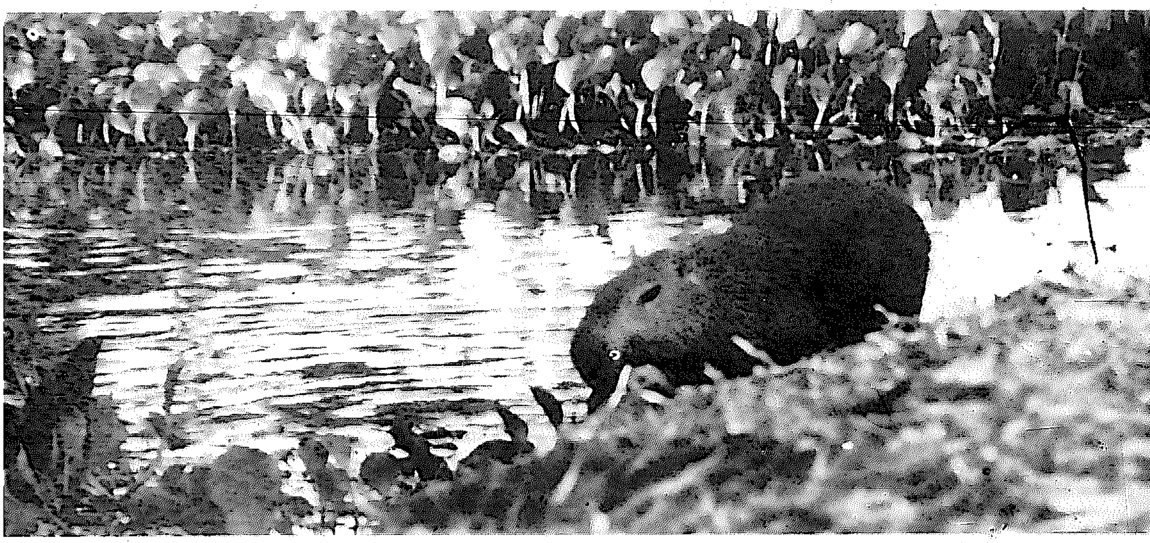
A robust, reddish, brown, muskratlike animal, the nutria can grow to be 1 m long and weigh 8 kg. It is a prolific breeder with webbed hind feet and a soft, but dense, underfur that is used in the fur trade. It has long been



Even sunbaked water hyacinth is consumed by donkeys near Khartoum, The Sudan. Lacking other herbage for much of the year, donkeys on the Nile River bank support themselves on the desiccated residue from previous harvests of aquatic plants. (N. D. Vietmeyer)

domesticated. Its pelt was so much in demand a century ago that it was introduced into Europe and North America. Some animals escaped and are now considered pests because they compete with native wildlife, damage crops, and erode canal banks.

Indeed, nutria can be as troublesome in waterways as the black rat (*Rattus rattus*) is on dry land. *The nutria should never be introduced into new regions until extensive ecological studies are undertaken.* In New World developing countries where it now exists, however, research on nutria management may help reduce aquatic weed infestations and provide fur and meat. Nutria are



The capybara and an area cleared of water hyacinth, Venezuela. (J. Ojasti)

The nutria. (G. Gresham)

Growing on wastewater from a Florida dairy farm, a vigorous stand of water hyacinth is heavily grazed (foreground) by nutria. (L. N. Brown)

eaten in many parts of South America, and the animal offers an efficient method for converting aquatic weeds into food.

Nutria feed heavily on duckweed. Though they graze only on fresh tender roots and water hyacinth leaves, they nevertheless reduce the plant's vigor and spread.

Woody plants found along the shoreline are relished by nutria. Cattails, bulrushes, and reeds are cut to the ground and the soft lower stems and starchy rhizomes devoured. This can greatly reduce the weed problem.

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Part II

Harvesting and Using Aquatic Weeds

7 Harvesting

Removing aquatic weeds from the waterways and selling or utilizing them to defray the cost of removal is an appealing concept. It would result in weed-free waterways while providing an extensive vegetation resource (especially advantageous in developing countries where forage and fertilizer are in short supply). Additional advantages of harvesting over other approaches to aquatic weed management include the following:

- possible, but not yet proven, low net cost;
- reduced dependence on foreign exchange (harvesting reduces the need for imported chemical herbicides);
- adaptability to labor-intensive techniques as well as to capital-intensive techniques;
- compatibility with fish (harvesting can be controlled to leave enough vegetation to benefit and maximize fish production);
- compatibility with terrestrial crops growing near the waterway (unlike some herbicides);
- ability to be introduced rapidly to give quick and predictable removal of weeds from specified areas (unlike with biological controls);
- ability to remove pollutants from the waterway (see Chapter 13); and
- production of useful materials.

Aquatic plants are harvested from a site at the water's edge or with a self-propelled, floating harvester. Shoreside harvesting requires that the plants float to the harvester. Rooted species must be uprooted or mowed and then moved to the harvester by boat or by wind and current. Plants can be lifted from the water by hand, crane, mechanical conveyor, or pump.

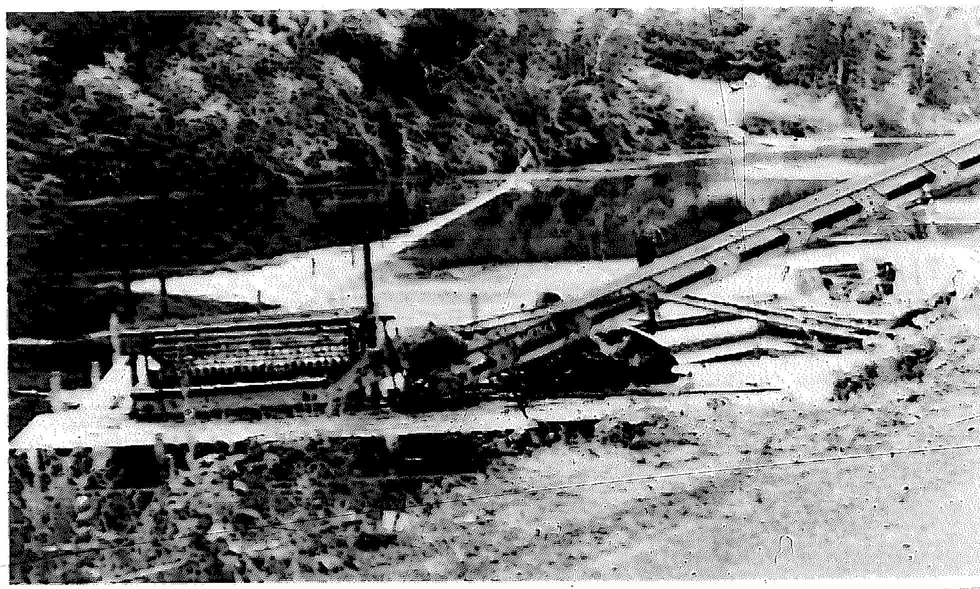
Mobile harvesters are usually expensive machines that sever, lift, and carry plants to the shore. Most are intended for harvesting submerged plants, though some have been designed or adapted to harvest floating plants or the mowed tops of submerged plants.

Handling the harvested weeds is a problem. Transporting the plants is difficult and expensive because of their enormous water content. Choppers are often incorporated into harvesting machinery designed for aquatic plants. Chopping makes the plants much easier to handle and reduces their bulk to less than a fourth of the original volume, greatly simplifying transportation, processing, and storage.

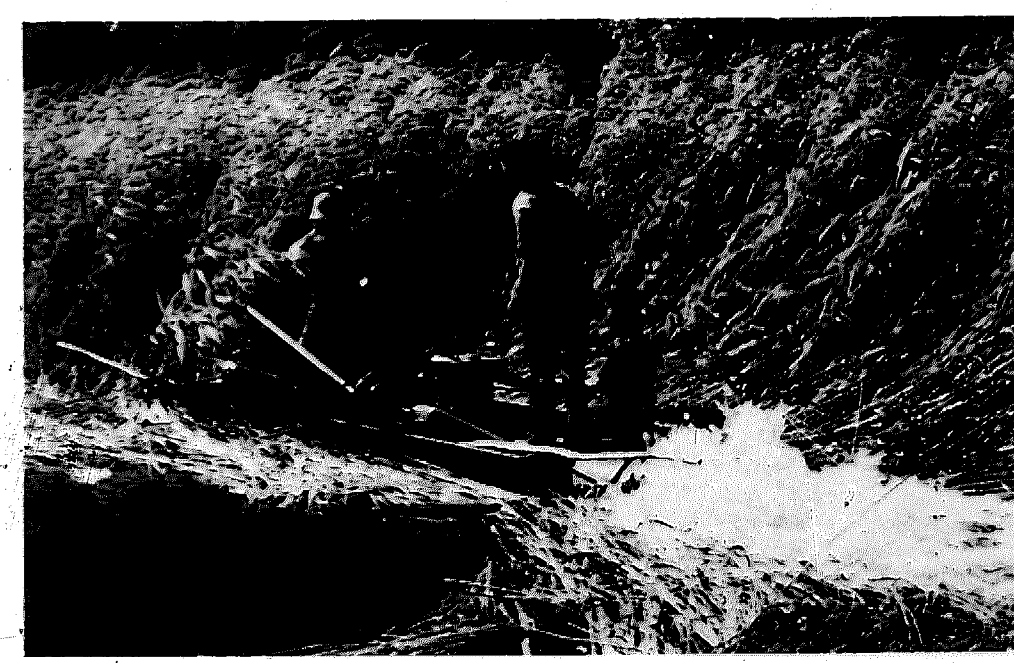
Some examples of techniques for harvesting aquatic plants are shown in the chapter illustrations.

Hand harvesting may supply enough feed or soil amendment for small farms. Beira Lake, Sri Lanka. (N. D. Vietmeyer)

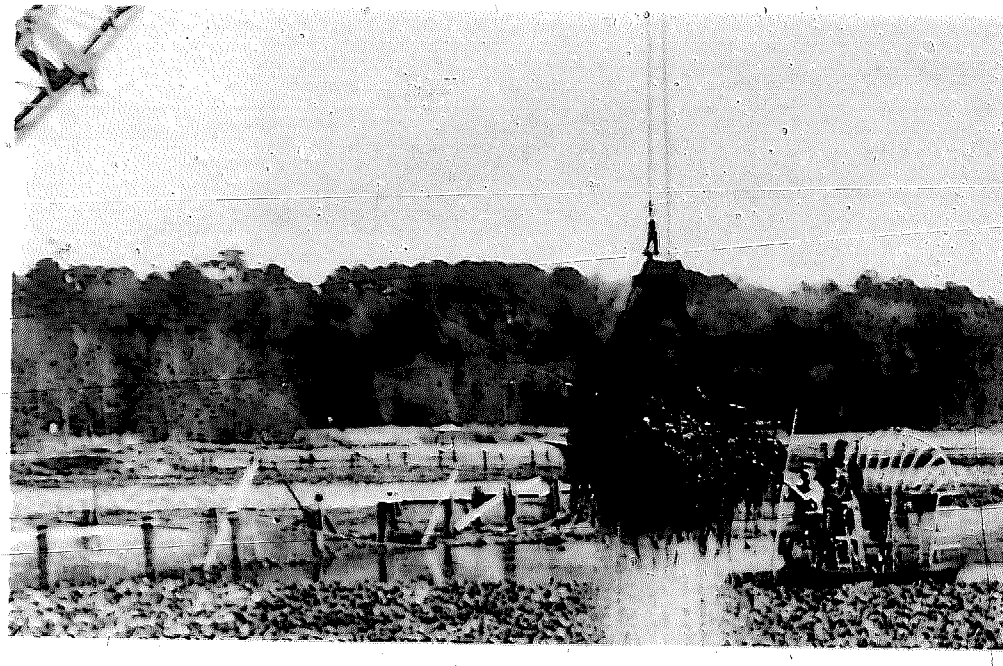
A rope threaded through cork floats, or a chain of barrels can be used as barriers to retard the spread of water hyacinth. (V. Myers)



A boom across a flowing river can divert floating aquatic plants to the shore where they can be harvested. Designed by University of Wisconsin students, this system collects and removes weeds from a narrow lake upstream. Many of the weeds are rooted and are mechanically mowed, allowing them to float to the boom. (R. G. Koegel)

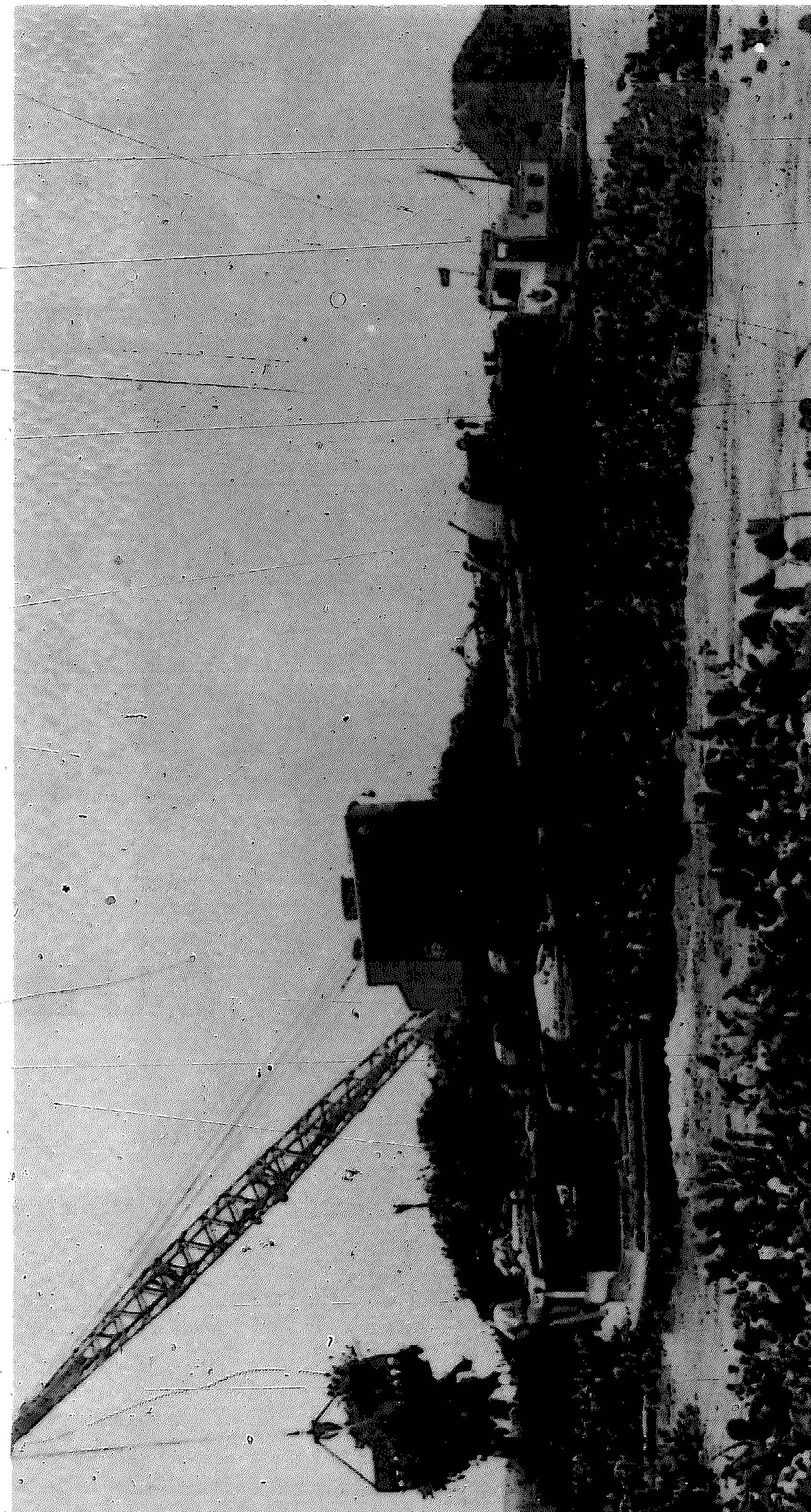


A small mowing boat, particularly suited to cutting reeds and other emergent aquatic weeds. (Krinke and Krüger G.m.b.H., Langenhagen, Federal Republic of Germany)



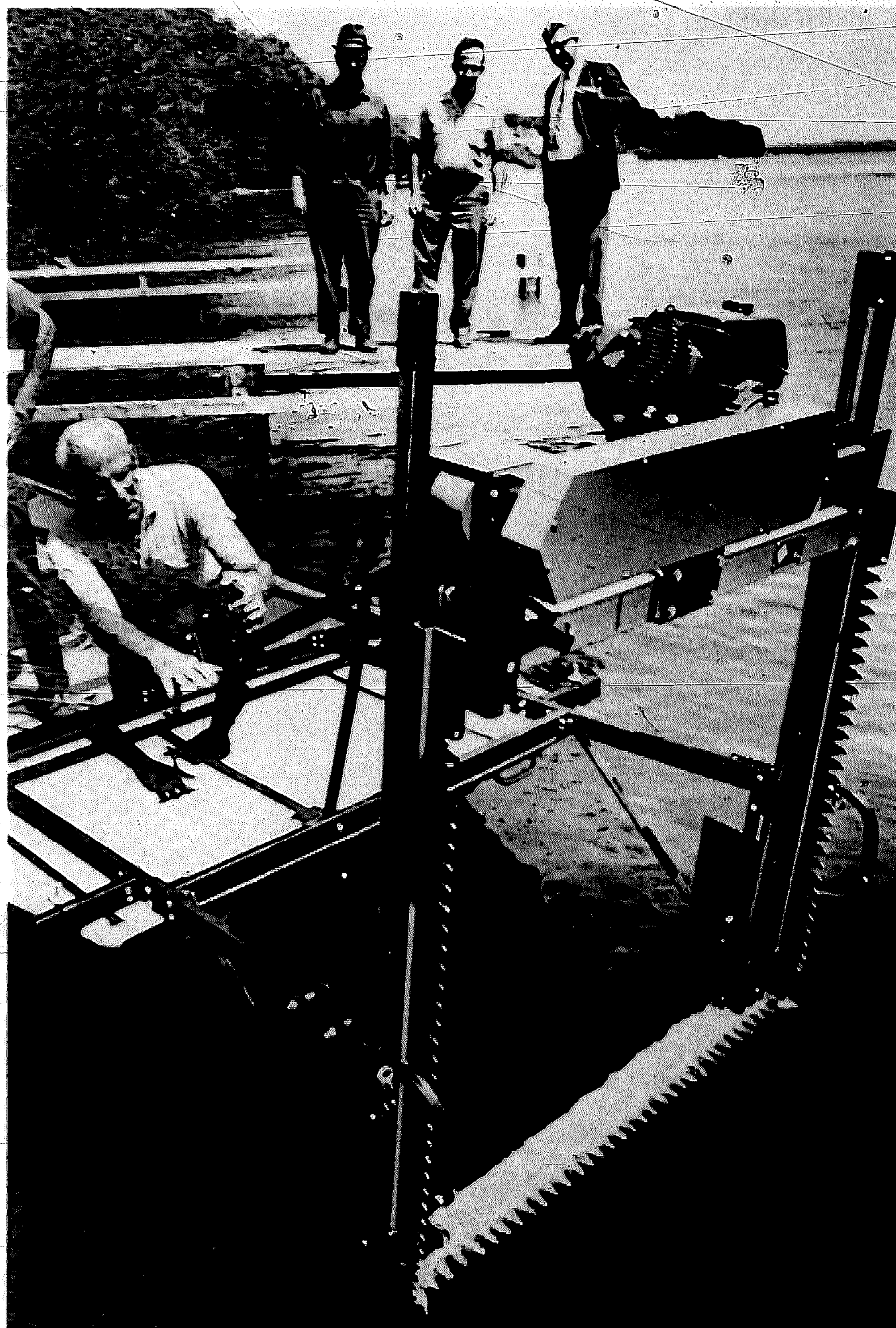
Specially designed for harvesting water hyacinth, a "clamshell" bucket improves the efficiency of a dragline removing the plants from Lake Alice, Gainesville, Florida. In the United States the so-called "Florida airboat" (background) has given aquatic weed workers the ability to maneuver in swamps and weeds. Thrust forward by a backward-facing airplane propellor, the airboat can move equally well over weeds and water. (L. O. Bagnall)

Tractor-powered, mobile harvester for water hyacinth or other floating aquatic weeds. (L. O. Bagnall)

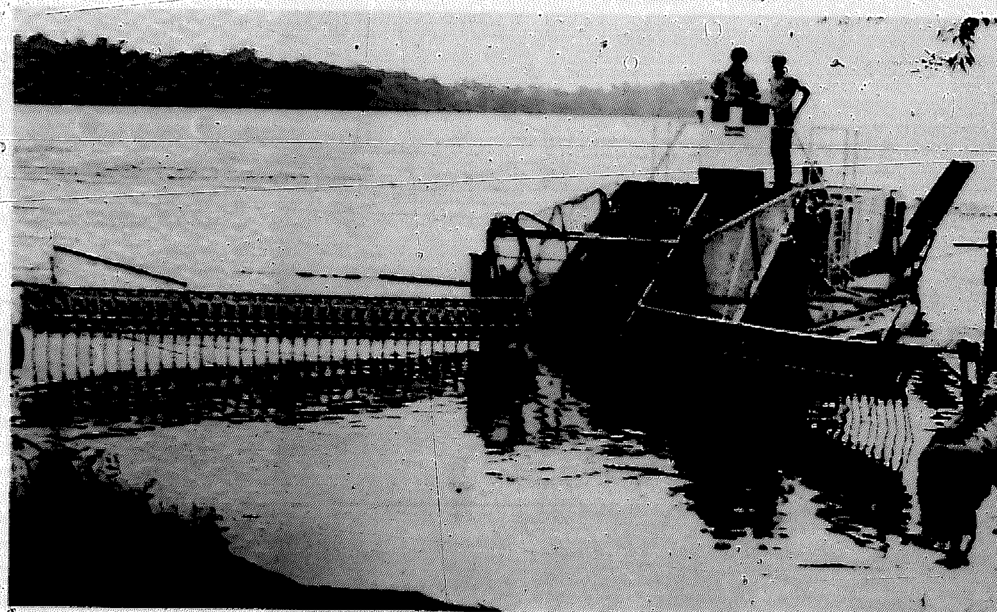


Before the advent of the major organic herbicide, 2,4-D in 1944, large harvesters were built in the United States to remove water hyacinth from navigation channels. Note the heaps of hyacinth in the background. (U.S. Army Corps of Engineers. Courtesy of N. R. Spencer)

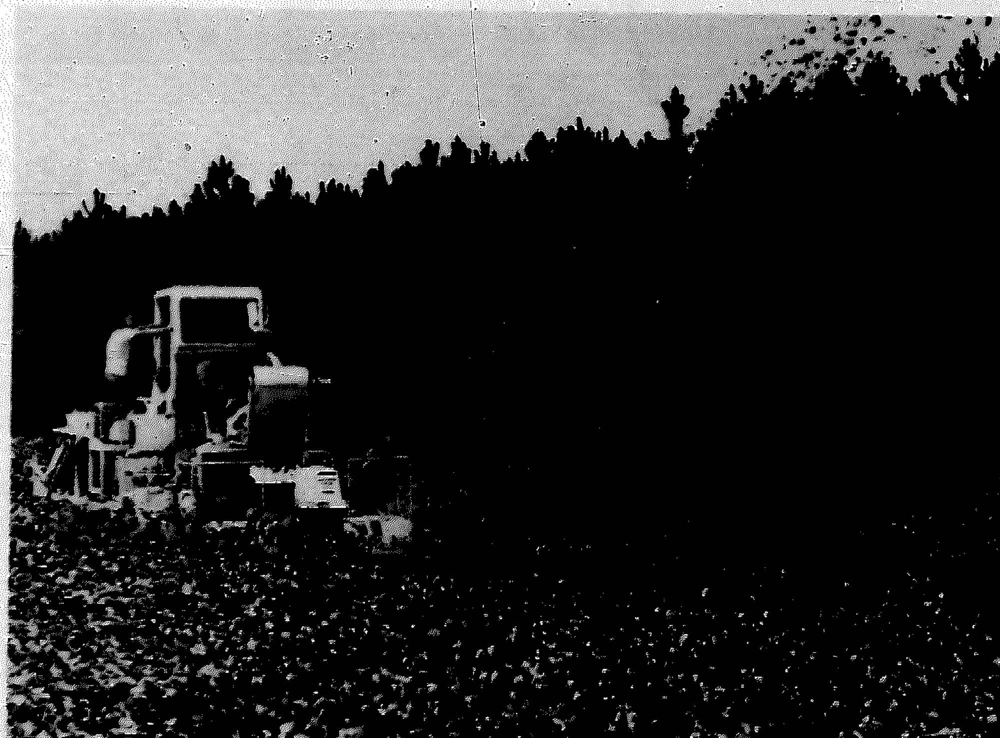
Conveyors with feeders require little energy to remove aquatic plants from the water and lift them to processing or transportation equipment. They can be made in a wide range of sizes and complexities. This one is on the St. John's River, Florida, USA. (Aquamarine Corporation)



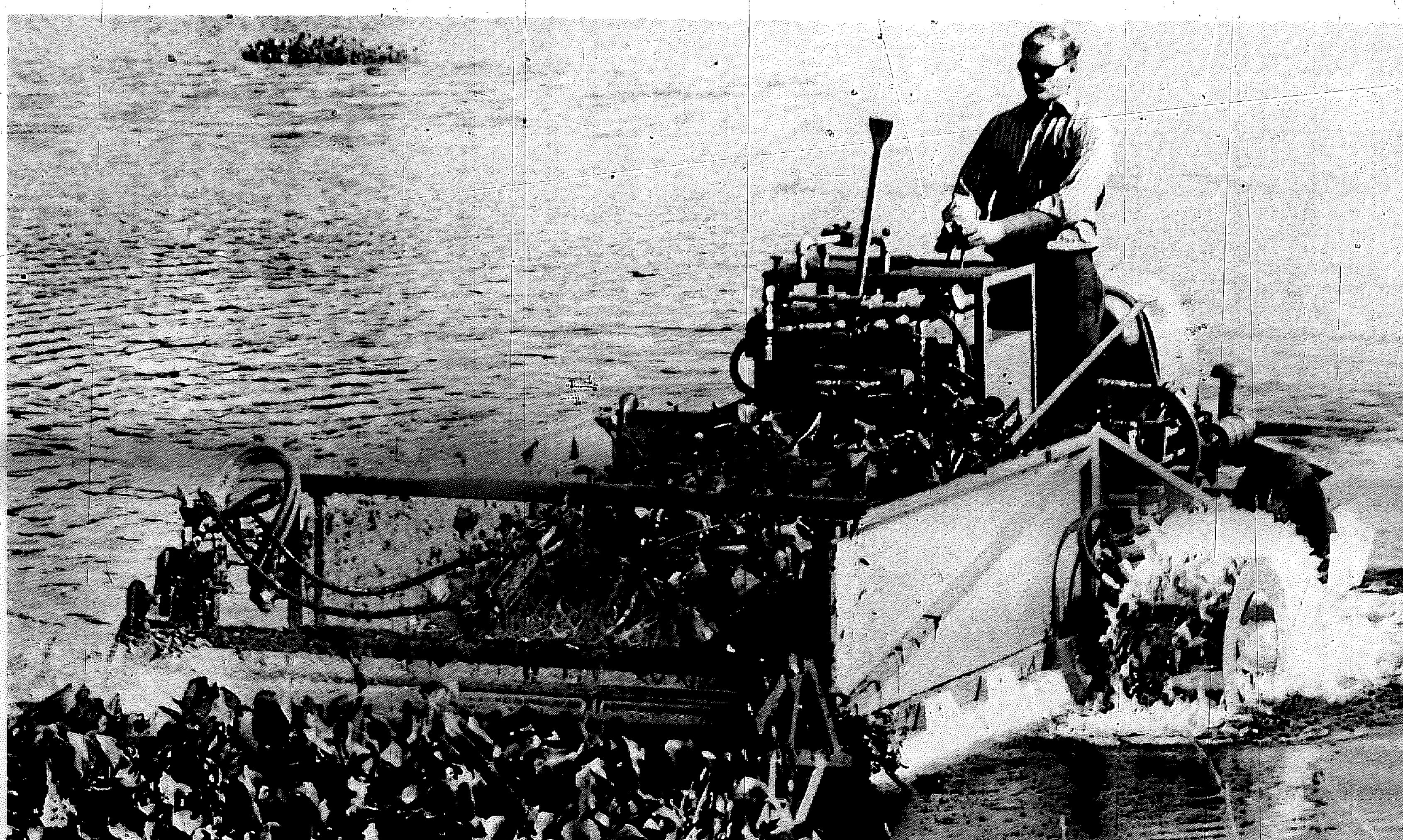
Cutterbars for mowing submerged aquatic weeds can be attached to small boats. Rakes for pushing the mowed vegetation to shore are usually attached to a second small boat. (Air-Lec Industries)



Large, complete floating harvesters for submerged aquatic plants are impressive but expensive and have modest capacity. (R. G. Koegel)



The Hyballer, a special water hyacinth removal machine that picks up hyacinth and throws it to shore. (Aquamarine Corporation)



An experimental harvester lifts, breaks, and throws water hyacinth by grasping and pulling on aerial parts of the plants, protecting the high-speed harvesting mechanism from damage by sudden underwater obstructions. (R. G. Koegel)

Recently flotation shoes have been made for recreational use. They can greatly help workers inspect and move around in aquatic weed patches. (N. D. Vietmeyer)

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8 Dewatering

As noted previously, aquatic plants may contain as little as one-sixth the amount of solids in land grasses. This is the main reason why they are not now harvested and used. Too much material has to be handled to get any useful amount of solid. When used as feed, for example, a massive 95 kg of water must be excreted by an animal for every 100 kg of fresh water hyacinth eaten. In order to make hay from aquatic plants, as much as 90 kg of water must be evaporated for every 100 kg of whole aquatic plants laid out to sun dry, and this must occur so rapidly that mold and decay do not ruin it (an impossibility in humid or cool climates).

Aquatic plants can be dewatered, however. About half the moisture is on the surface and some is loosely contained in the vascular system. This water can be removed relatively easily by lightly pressing the plant.* The press-water squeezed out contains only about 2 percent of the plant solids and often can be returned directly to the waterway without causing pollution.

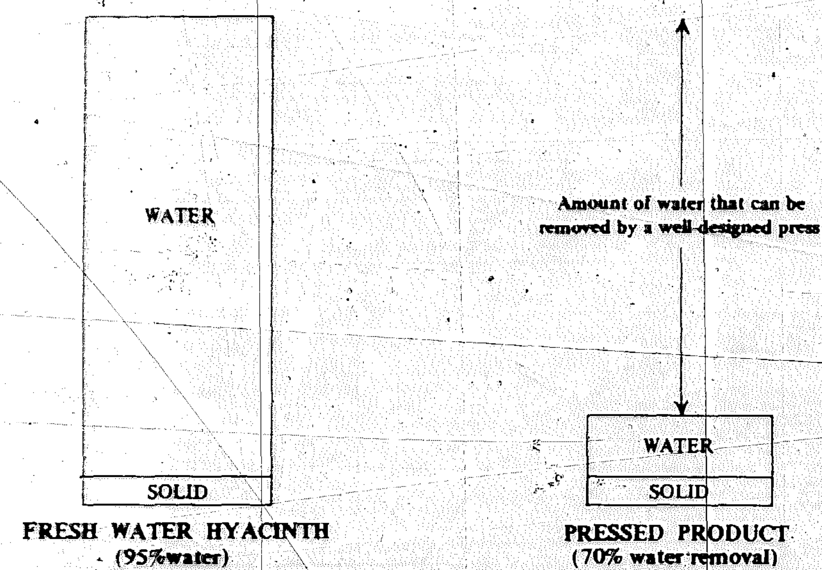
Even with half the water removed, aquatic vegetation may still be much wetter than terrestrial grasses. In order to reduce the moisture further, heavier pressing is required. This process can yield a product that is comparable to terrestrial forage grasses in moisture content (see figure page 80).

Depending on plant species, press design, and operating conditions, the water removed can carry with it 10–30 percent of the plant's solid matter, 15–35 percent of the protein, and up to 50 percent of the ash (for the most part silt and mineral encrustations caught on the plants). Roller-, belt-, cone-, and screw-presses have all been used to dewater and remove nutrients from vegetation, with varying success. All types are available commercially, but usually in heavy, durable designs that are unnecessarily complex and cumbersome for pressing aquatic vegetation. Lightweight experimental screw presses (suitable for use in developing countries) have been designed. For example, a small screw press of simple design (see illustration page 79) has been constructed at the University of Florida. With its 23-cm bore, this press weighs between 200 and 250 kg. Complete with power plant, it can be carried by truck, trailer, or barge to remote locations, and can press up to 4 tons of

*Although the term "pressing" is widely used to describe the process, pressing alone liberates little moisture and the vegetation must be "chewed," sheared, or macerated before the water can be pressed out.

Harvested from a small pond near Georgetown, Guyana, water hyacinth is fed to a small dewatering press. The pressed product contains less than half the water of the fresh weeds. With addition of a lawn-mower-type chopper, this small press can process 4 tons of water hyacinth each hour. (N. D. Vietmeyer)

chopped water hyacinth per hour. Such presses are compatible with a program of manual harvest and with the small-scale needs for animal feed in rural areas of developing countries. In addition, these presses can probably be manufactured in the country itself.



With a 90-95 percent water content fresh aquatic weeds can seldom be used for animal feed or most other purposes. Mechanical presses can squeeze the bulk of the water out, leaving a product suitable for converting into useful products.

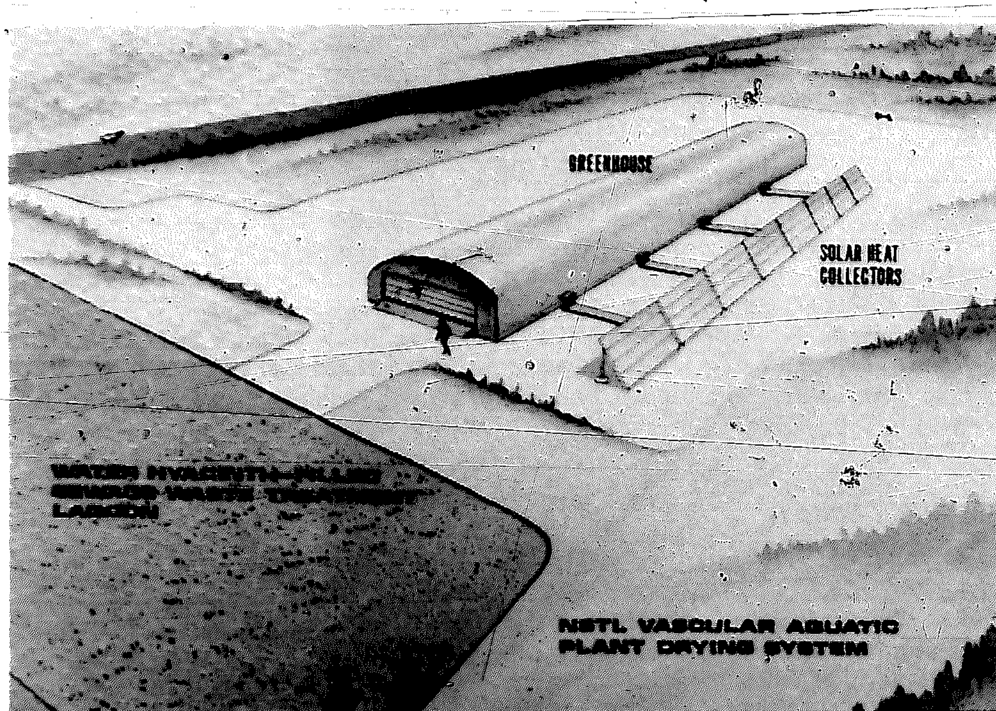
Estimates of water hyacinth pressing-costs range from US$5.00 to $10.00 per ton of dry matter, depending greatly on machine cost, machine use, production rate, amortization time, and labor costs. Less than 4 horsepower hours is required to remove a ton of water, leading to an energy cost in the United States of $2.25 per dry ton.

In some arid climates solar drying may be feasible, either by exposing a thin layer of the plants to the sun or by more sophisticated solar collector-heat transfer systems. In the United States, a solar drying system for aquatic plants is under construction at the National Space Technology Laboratories. Depending on the weather, it will be capable of drying 16-18 tons of newly harvested water hyacinth in 36-120 hours (see picture page 81).

Drying aquatic plants with conventional fuel-heated air is economically impractical because of the high moisture content.

Limitations

If press juice with a high solid content is returned to the water, it wastes potentially valuable nutrients and may pollute the water. In most cases, however, it will be less than the pollution caused by weed-control methods (e.g., chemical) that leave all of the vegetation in the waterway to rot.



Solar energy is being harnessed to dry aquatic weeds in experiments at the National Space Technology Laboratories near Bay St. Louis, Mississippi. This system is connected to a process that farms water hyacinth on sewage effluent. (National Space Technology Laboratories)

Research Needs

Dewatering aquatic weeds offers such promise that engineers in regions that have aquatic weed outbreaks are encouraged to build and test pilot-scale presses.

The subject of juice recovery is one for research; positive results will improve the efficiency of mechanical dewatering of aquatic plants. Though in the juice the solids are very dilute they may have some profitable uses.

Combining mechanical dewatering with solar drying is a promising avenue for research.

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9 Soil Additives

Mineral fertilizers are too expensive for many farmers in developing countries, yet there is a greater need now than ever to increase food production. As an alternative, the 1974 World Food Conference and, more recently, the Food and Agriculture Organization of the United Nations (FAO) have stressed the urgency of reassessing organic fertilization. This includes green manuring and composting; aquatic weeds can be used in both processes.

Aquatic weeds can be used as green manure through a simple process—the plants are either applied to the soil as a surface mulch or they are plowed under or buried by hand in shallow troughs. As a mulch, they suppress weeds, reduce evaporation, and reduce rainfall runoff and the erosion it causes. The problem with this method is that the plants are bulky and difficult to handle and large amounts have to be transported.

Compost is decomposed animal and plant matter for use as garden fertilizer and soil conditioner. Composting is an ancient practice known at least since biblical times, but only in recent years have aquatic weeds been used, and then only sporadically. Nonetheless, the few experiments conducted to date show that the process is one of the simplest and most useful techniques for using these weed pests.

The weeds are harvested and spread out at the water's edge for a day or two. Then the wilted plants are made into a pile with some soil, ash, and a little animal manure. Microbial decomposition begins spontaneously and the resultant bacteria and fungi break down the lipids, proteins, sugars, starches, and cellulose fiber. The piled composting mass retains heat and so encourages microorganisms to multiply. Although compost can be made in the absence of air (see Chapter 12), the most common technique involves frequent turning of the pile to maintain aerobic conditions. Tropical temperatures (especially the warm nights) foster decomposition. Warming occurs and temperatures in the middle of the pile may go to 70°C. At such temperatures only special heat-loving bacteria and fungi survive. Others that are pathogenic to humans and animals are killed, as are weed seeds and parasite eggs. In the rotting mass the fibrous weeds decompose, shrink, and crumble into an earthy-smelling, dark-colored, soil-like compost.

Some developing countries have a long tradition of using compost made from other waste materials. Compost raises soil fertility and improves yields, but most of all it improves soil quality (by improving soil aggregation and stabilizing the soil structure). It increases the soil's capacity to absorb and store water (particularly important in sandy soil); it enhances aeration and favors growth of soil microbes (particularly important in heavy, claylike soils); spread on the soil surface, it reduces evaporation, erosion, soil aggregation, and crusting (particularly important in the lateritic soils, widely spread throughout developing countries); and it can help return saline soils to production.

Compost fits a need in the developing world where commercial fertilizer is expensive, labor cheap, implements simple, and soil structure and water retention a problem. Compost is easily made using manual labor without expensive equipment. Composting can be done on a small or large scale. The fact that compost requires much moisture makes it an ideal use for aquatic weeds—the weeds do not have to be dewatered (see Chapter 8) except by a few days' wilting in the sun, a great savings over other uses in terms of cost and equipment.

The microbes that produce compost need nutrients (especially carbon and nitrogen), oxygen, and moisture. Luckily, aquatic weeds generally contain adequate nutrients (the ratio of carbon to nitrogen is usually in the appropriate range, i.e., less than 30), especially if they have been growing in nutrient-rich waters. They are also low in lignins, the plant constituents that most resist composting.

One report from the Philippines has described the successful use of dried water hyacinth as a bedding material for cultivating mushrooms (*Volvaria* spp.)*

Limitations

Although compost and green manure improve soil quality, the improvement is less than that obtained from mineral fertilizers. This is because compost usually contains 1.5-4 percent nitrogen, 0.5-1.5 percent phosphorus, and 1-2 percent potassium, whereas mineral fertilizers are severalfold more concentrated. (However, it is thought that 25-30 percent of the mineral fertilizer nutrients leach to the groundwater and are lost to the crop.) Compost nitrogen is in organic form (particularly as protein) and is released into the soil only gradually. In about a year, however, all the nitrogen does become available. (This may be an advantage because it extends the availability of nitrogen throughout the growing season.) Compost is bulkier

*Abstract 12 in Ratchanee. 1972. (See Selected Readings.)

To make compost, the Home Gardens Division of the Sri Lanka Department of Agriculture uses chopped water hyacinth and city refuse (together with small amounts of ash, earth, and cow manure). Shown here are the compost piles, and the tools required to make them. Using simple, labor-intensive techniques the compost is made in as little as 12 days. Each month over 80 tons of compost are made and sold (under the brand name KASALA MENIK or "garbage gems"). (V. E. Dalpadado)

than fertilizer and, because it has a lower concentration of plant nutrients, large quantities may be needed. Since it can be time-consuming and expensive to apply, composting is most attractive in areas where labor is cheap and plentiful.

In order to derive the most benefit, compost must be made and managed carefully. Some farmers may be unwilling to expend the necessary time and effort. Though aquatic weeds need not be dewatered, composting must be done carefully to avoid waterlogging and resulting anaerobic conditions, which produce foul odors.

Aquatic weeds harvested from waters that contain toxic pollutants may produce compost that is a hazard to humans, animals, crops, or the environment in general. This is not a common occurrence, but in the vicinity of industry, mining operations, or other sources of pollutants, analyses of the weeds and of their compost must precede their use. In areas where parasites and pathogenic bacteria infect the waters, care must be taken to ensure that the fermentation temperature rises and pasteurizes the compost. Failing this, the material should be stored over a period of six or seven months and finally

The project in Sri Lanka uses the water hyacinth compost to raise vegetable seedlings. Sold to urban dwellers in Colombo and its suburbs, the seedlings are planted in window boxes, on roof tops, and in small backyards. The vegetables produced are a cheap source of nourishing food. (V. E. Dalpadado)

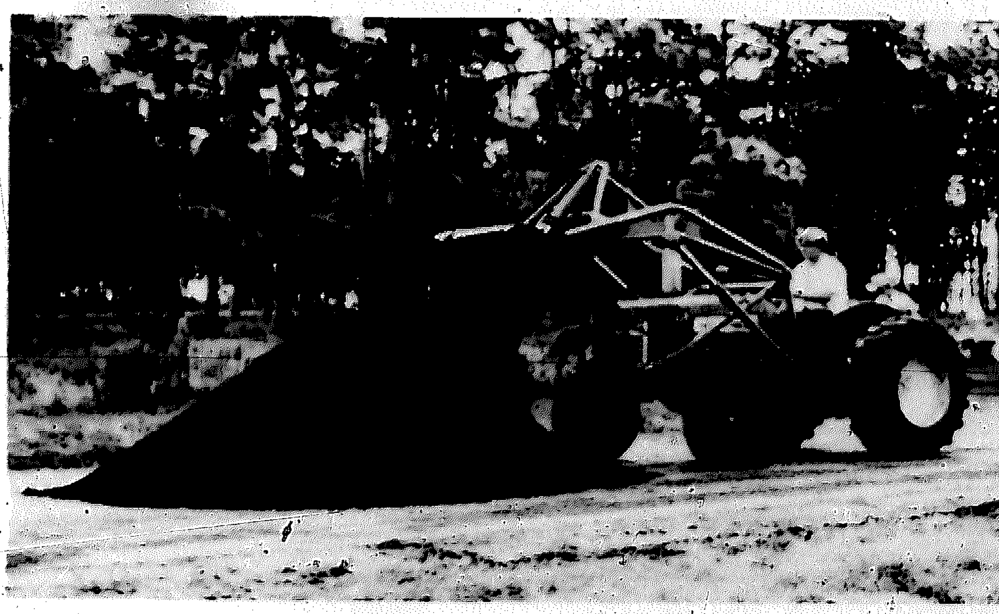
dried by spreading as a thin layer so that it can be thoroughly irradiated by the sun.

Composting water hyacinths presents a problem: The fiber is not degraded. Composted water hyacinth roots, however, have been used as a propagation medium for houseplants. An article from Puerto Rico reports them to be as good as German peat moss,* but another from Florida reports that, in the root medium, houseplants grew well but lacked the normal green color, possibly due to a manganese imbalance.†

Research Needs

Little or no basic research is needed on the composting of aquatic weeds. The processes and techniques are well-known from their use with other materials. Instead, horticulturists, agronomists, and agriculture extension workers should undertake trials using locally available aquatic weeds and standard composting techniques (see Selected Readings). Governments of developing countries should promote the utilization of the results of these trials.

*Rodriguez et al. 1973. (See Selected Readings.)
†Conover and Poole. 1974. (See Selected Readings.)



In a commercial operation in the United States (Sarasota Weed and Feed, 1835 North Washington Boulevard, Sarasota, Florida 33580, USA) water hyacinth is harvested, chopped, lightly pressed (for ease in handling) and trucked to an unused stretch of road. Here it is piled and left several months to compost. The product finds a ready market as a peat moss substitute. Nurseries use it to manufacture "peat" pots and potting medium for growing seedlings. (J. R. Leach)

Added to the soil on the left of the picture, compost made from aquatic weeds resulted in a vigorous improvement in plant growth. (R. G. Koegel)

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10 Processed Animal Feeds

Many types of vegetation that humans find inedible can be converted into meat, milk, and wool by ruminants (cud-chewing animals, such as cattle, sheep, and goats). It is therefore reasonable to consider aquatic and semi-aquatic plants as potential ruminant feed, particularly as cattle, water buffalo, and other animals are known to graze the leaves of floating aquatic weeds (see Chapter 6) and some semi-aquatic plants. The meat and milk produced by these animals is needed by peoples in developing countries, who get only a fourth as much animal protein per day as those in the rest of the world, partly due to animal feed shortages.

As mentioned in the Introduction and Summary to this report, aquatic weeds are usually between 10 and 26 percent crude protein (dry matter basis), which is equivalent to, or higher than, that of forages. The leafy parts of aquatic plants, such as duckweed and water hyacinth and some submerged weeds, contain 25–35 percent protein, which is exceptionally high. The individual amino acid constituents are present in about the same proportions as in land forages of similar crude protein content; however, the levels of methionine and lysine—generally considered the limiting amino acids in plant proteins—are often lower than in high-quality terrestrial crops.

Nevertheless, many aquatic plants have not been analyzed for amino acid content and that some may be surprisingly good is suggested by a lysine content in water hyacinth equal to that found in milk.*

The weeds differ widely in fiber content. Submerged weeds are low in fiber because the water supports their weight, but floating and emergent weeds (except the tiny duckweeds) need fiber as a skeletal support. Reeds, cattails, and other tall weeds contain extreme amounts of fiber. The fiber content of such aquatic plants makes them potential substitutes for hay, cottonseed hulls, and other roughages eaten by ruminant animals.

Some submerged aquatic weeds, such as hydrilla and water milfoil, are particularly rich in carotenes and xanthophylls and could become new sources for these commercially valuable pigments, which many countries add to poultry rations.

*Taylor and Robbins. 1968. (See Selected Readings.)

While such potentially toxic substances as nitrates, cyanides, oxalates, tannins, and dicoumarins are at times present, they also occur in many terrestrial forages, and in general aquatic weeds do not appear to be any more hazardous as feedstuffs than conventional forages.

Nutrient composition is a guide to a feed's value, but high digestibility is crucial if the nutrients are to be available to the animal. The digestibilities of only a few aquatic weeds are known. For water hyacinth the organic matter digestibility by rumen microbes of the fresh whole plant, leaf, petiole, and submerged parts were 55.7, 50.8, 58.7, and 51.2 percent, respectively, in one experiment. This indicates that, for a roughage, the nutrients are satisfactorily available to ruminants.

In Southeast Asia, some nonruminant animals are fed rations containing water hyacinth (see illustration page 59). In China, pig farmers boil chopped water hyacinth with vegetable wastes, rice bran, copra cake, and salt to make a suitable feed. In Malaysia, fresh water hyacinth is cooked with rice bran and fish meal and mixed with copra meal as feed for pigs, ducks, and pond fish. Similar practices are much used in Indonesia, the Philippines, and Thailand.*

Despite these promising beginnings, many attempts to feed aquatic plants to animals have failed.† The failure is apparently due to two features—the high moisture content of aquatic weeds and their high mineral content. For success, any program to utilize aquatic plants must overcome these two difficulties.‡

Moisture Content

In their fresh state, most problem aquatic weeds are as much as 95 percent moisture. The high moisture content and consequent bulkiness makes aquatic weeds cumbersome, expensive to transport, and impossible to store without mold forming.

In order to make animal feeds from the huge quantities of aquatic weeds that occur in many countries, methods for reducing the moisture content must be used. These are discussed in Chapter 9. Several approaches are known for making feedstuffs from dewatered aquatic plants.

- Weeds, partially dewatered by chopping and pressing, can be fed directly to livestock. Surprisingly, this has seldom been tried in developing

*Anuwar bin Mahmud. 1967; Hora. 1951; and Villadolid and Bunag. 1953. (See Selected Readings.)
†See, for example, Hosain. 1959; and Loosli et al. 1954. (See Selected Readings.)
‡Panel member D. D. Culley reports that he has found that swine readily eat wet duckweed.

countries. It seems likely that cattle, water buffalo, goats, sheep, donkeys, and swine could use partially dewatered aquatic weeds in their diets when forage or other nourishment was not readily available. This is particularly likely during dry seasons in such countries as Sudan and Bangladesh.

• Partially dewatered weeds can be sun-dried to hay. Rapid spoilage makes this difficult to do in the humid tropics, but it appears a promising technique for less humid climates.

• Partially dewatered weeds can be further dried using hot air to yield a stable product that will not mold when stored. It can also be ground into a meal or pelleted for bulk handling. This energy-intensive method is likely to be of little value in developing countries.

• Partially dewatered aquatic weeds can be ensiled. In this process, the weeds are preserved by organic acids produced in fermentation. The weeds are placed in a silo, and the naturally occurring bacteria ferment the plant components to produce lactic acid and other organic acids. This process takes about 20 days. Extensive experiments in Florida have shown that pressed water hyacinth produces a palatable, digestible, and nutritious silage that is readily accepted by cattle and sheep. The first large-scale production of water hyacinth silage occurred in Florida in 1972. It was made in barrel-sized silos, in a full-sized tower silo, and in stacks piled on the bank of a waterway. No fundamental problems were encountered. For successful ensiling, the moisture content of the material must be less than 80 percent—otherwise it turns liquid and foul-smelling. But water hyacinth silage can be made successfully using material with an 85–90 percent moisture content—the hyacinth fiber retains water remarkably well; water does not separate to cause anaerobic conditions.

Ensiling aquatic weeds could become particularly important in humid tropical and subtropical regions where it is difficult to make hay. Because silage is bulky, silos must be located near the aquatic weed supply and also, if possible, near the market or animals to be fed. Stack or tower silos can be built on most sites regardless of the level of the water table. One advantageous location for a silo might be near a lagoon where water hyacinth or other aquatic plants are grown to remove pollutants from wastewater (see Chapter 14).

• Aquatic weeds can be preserved by adding commercially available preservatives to the silage. Preservatives containing propionic, acetic, or formic acids applied under carefully supervised conditions to dewatered water hyacinth have produced good-quality feed. The acids inhibit undesirable bacteria and molds and keep the fermentation temperature within a desired range. Acid-preserved silages made from water hyacinth are palatable and have been readily accepted by cattle and sheep.

Mineral Content

[illegible] aquatic plants can contain enormous quantities of minerals depending on the plant type and on the conditions of its waterway. The ash content of an aquatic weed can be as high as 60 percent if it is a submerged plant or a floating plant with long roots, covered in sand, silt, and encrusted carbonates. Such plants make unsuitable animal feeds and have sometimes led [illegible] to conclude that aquatic weeds cannot be used as feedstuffs. For example, in recent decades several attempts to feed water hyacinth to animals [illegible] that success depends upon selecting the [illegible] at the right stage of growth. Lush, succulent, tall-stemmed hyacinth

Cattle feeding on rations that are 10 percent dried water hyacinth. The hyacinth was grown on digested wastewater from the city of Lucedale, Mississippi, USA. (National Space Technology Laboratories) growing on nutrient-rich waters make much better feed than dwarfed water hyacinth plants, which usually have long roots encrusted with silt and carbonate deposits.

Even the mineral content within the plant itself affects its feed value. In experiments in Florida, the mineral contents of six aquatic weeds (including water hyacinth and hydrilla) were measured throughout a year. Phosphorus, magnesium, copper, zinc, and manganese were present in about the same concentrations as they are in land forages; however, sodium was 10–100 times higher, iron 4–19 times higher, and potassium 3–6 times higher. Calcium was also higher.* Part of the reason why animals refuse to eat large quantities of such aquatic plants is thought to be the overabundance of these minerals–an animal getting only 10–20 percent aquatic plants in its diet would be receiving its full requirement for these minerals. A mineral imbalance may result if this level is exceeded.

The feed value of an aquatic weed is site-dependent; the mineral content reflects the dissolved minerals in the waterway. In general, however, while aquatic weeds can be used to supplement animal feeds, they cannot comprise the entire diet because of the high mineral content.

Limitations

Traces of pesticides have been found in samples of aquatic plants; consequently, the plants must be tested for pesticide residues before being processed into animal feed. Residues are not likely to cause a problem unless the plants had been chemically treated immediately prior to harvesting, or are growing in an agricultural area that receives regular applications of insecticides.

Canals and waterways that are excessively polluted with animal or human waste may contain pathogenic bacteria. Aquatic plants harvested from such waters should be screened for harmful bacteria before being used in animal diets or being handled by man.

Success in ensiling depends on achieving successful fermentation. Most plants must first be chopped and packed firmly into a silo or stack. Then in order that fermentation proceed, carbohydrate must be present in sufficient quantity for the microorganisms. Aquatic weeds are often low in fermentable carbohydrate, and feed ingredients high in starch or sugar must be mixed with the plants as they are placed in the silo. Aquatic weeds with a high moisture content may require the addition of absorbent materials, such as dried industrial mill by-products. In Florida, dried citrus pulp and sugarcane

*Information supplied by R. L. Shirley.

molasses have been added to water hyacinth pressed residue as sources of carbohydrate and absorbent. By-products of the rice, grain, and sugarcane milling industries and waste cassava (manioc) are all potential substitutes.

Research Needs

Nutritional investigations of all aquatic plants having potential as animal feeds should be initiated. Priority should be given to the floating plants that may be consumed in their natural state, such as duckweed grazed by geese and water hyacinth leaves grazed by ruminants (see Chapters 5 and 6). Studies of nutrient content and digestibility should be accompanied by engineering studies to develop superior harvesting and processing methods (see Chapters 7 and 8) that produce nutritious, palatable, digestible feedstuffs.

The quantities of inorganic minerals in aquatic plants need to be measured and exploratory projects launched to test the use of aquatic plants as sources of supplementary minerals in animal diets. Research is needed on the digestion, absorption, and metabolism of these minerals by various species of domestic animals and fish. These measurements should be made on different parts of the plants, for example on the leaves and on the roots of water hyacinth, because it may be best to use them separately, if the mineral content varies widely.

Research is needed on methods of ensiling aquatic plants with indigenous materials that provide carbohydrates for fermentation. If highly absorbent additives could be found, water hyacinth might be used for silage without any preliminary dewatering, greatly simplifying the process.

Nitrate, cyanide, oxalate, tannin, and dicoumarin concentrations should be investigated in plants that have not yet been tested and in new water sources for those that have.

The amino acid composition and cell wall content of various species of aquatic plants should be determined. Their effectiveness in the diets of various farm animals and fish should be evaluated. The amino acid and cell wall content should be checked for seasonal changes and effects of the fertility of the water in which the plants are grown.

Almost all the research on feeding aquatic plants to animals has focussed on available weeds. Many of these are not good animal feeds, and a promising research avenue is to test the aquaculture of aquatic plants selected specifically for their feed value. A fascinating account of such an approach is given by D. W. LeMare (see Selected Readings). He describes how, in the 1950s, businessmen near Penang (Malaysia) developed an intensive farming system that lagooned all animal manure and grew water spinach *Ipomoea aquatica* in the nutrient-rich waters (see illustrations page 124).

Water spinach can be used as animal feed directly without dewatering or ensiling—indeed it can be used as a green vegetable for humans (see Chapter 14). It also makes good food for herbivorous fish (such as those described in Chapters 1 and 2).

Other edible plants described in Chapter 14 may also make useful aquatic crops for animal feed, but local species should always be sought: *aquatic plants should not be introduced into new areas. The risk of their becoming weeds is too great!*

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11 Pulp, Paper, and Fiber

Tall, grasslike, emergent aquatic plants cover and clog vast areas of marshes and swamps the world over, often impeding agriculture, fishing, recreation, wildlife, and navigation. For decades these weeds have withstood destruction by fire, machines, or chemicals. Reeds, bulrushes, cattails, and papyrus usually grow in pure stands and have been harvested for centuries for food and fiber. As synthetic materials become increasingly expensive in the future, these aquatic plants may be used for those purposes again.

The Common Reed

The most impressive use of a wetland plant is the Romanian government's program to produce pulp and other cellulose derivatives from the common reed *Phragmites communis*. More than 60 percent of the huge (4,000 km^2) delta of the Danube River is covered in *Phragmites*. In 1956 the government began to farm and use it, and now the reed beds are carefully managed and their productivity improved.

The reeds are harvested, stored, and transported with machinery and techniques designed specially for the marshy terrain by the Danube Delta Institute, at Tulcea.

Harvested reeds are converted to pulp in mills at Braila, a short distance inland. Printing paper, cellophane, cardboard, and various synthetic fibers are derived from this pulp. The raw reeds and pulpmill wastes yield a variety of other products, notably cemented reed blocks and compressed fiberboard; furfural, alcohol, and fuel; insulation material; and fertilizer. With an annual harvest of about 125,000 tons, farming of the Danube reeds has become vital to the Romanian economy.

Extensive stands of *Phragmites communis* grow on lake margins throughout the temperate and subtropical regions of the world (except the southern part of South Africa). In some areas they cause massive and seemingly intractable problems. The Romanian example illustrates to the world how a reed-filled wetland can be turned to a resource without draining it and totally altering its character.

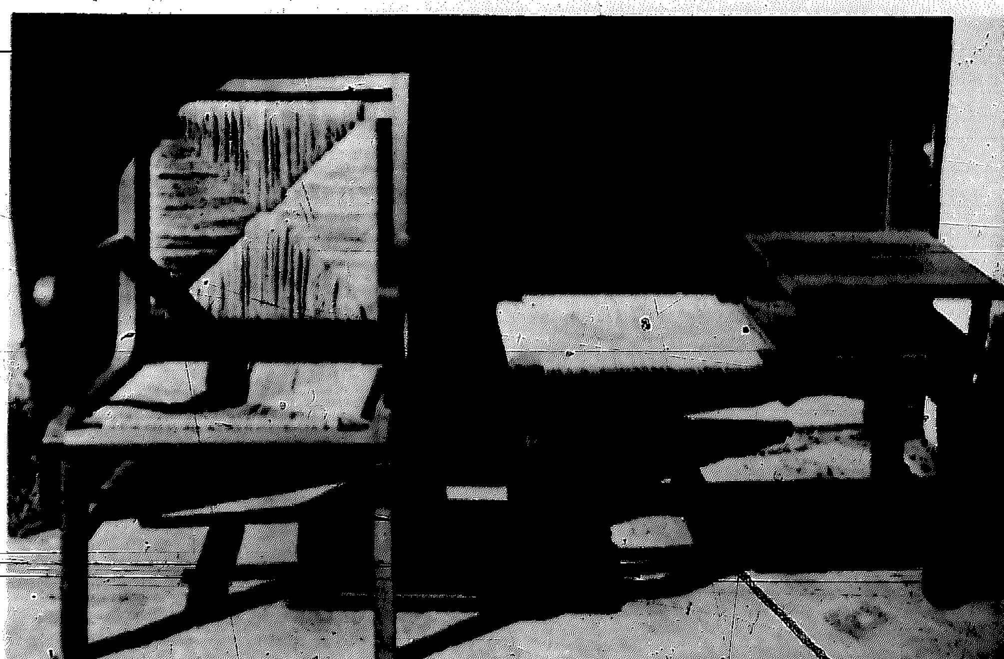
Harvested stems of the common reed awaiting hauling by barges to the cellulose processing plant in Braila, Romania. Annually, approximately 120,000 tons of dry reed is harvested and processed yielding 80,000 tons of dry pulp. In Europe, reeds have been harvested for centuries to provide roof thatch and other construction materials. (A. A. de la Cruz)

The Romanian system of reed farming is based on the reed's natural production cycle. The reeds are harvested in winter after they have shed most of their leaves. Then without further attention (e.g., plowing, fertilization, or chemical treatment) they are left to grow back naturally from their underground rhizomes during the spring and summer. At present, only 12,500 ha of 190,000 ha reedlands is harvested each year.

An elaborate gathering and transportation system is maintained. It includes three types of harvesters (tractors for harvesting dry land, airboats for harvesting swampy areas, and floatable balloon-tired vehicles for harvesting floating islands), floating quarters for crew, and fleets of barges. The air-dried reed reportedly yields 60 percent of unbleached pulp. The Braila factory pays $85 per ton for raw reeds—high by world standards, reflecting the government's partial subsidy of the project. Most of the reed pulp is mixed with wood pulp to increase the tear strength and the density of the paper that is made from it.

The common reed can produce many other products. For centuries it has been used for peasant crafts, thatching, fences, and windbreaks. Its stems are still used in basket work; as firewood, fishing rods, and weaver's spools; and as mouthpieces for musical instruments. Also, its roots are edible and the tender buds reportedly are used in salads in Indochina and the Soviet Union (Kirgiz Province). The Ma'dan tribe or "marsh Arabs" of southern Iraq

Anamese women weaving mats from aquatic reeds, Chantiburi, Thailand. (H. Popenoe)



Chair and table "caning" made from cattails (*Typha domingensis*) "Viveros la Pica," Venezuela. (J. Morton) construct houses out of *Phragmites.* They feed the young tender shoots to cattle.

Reportedly *Phragmites* is rich in pentosan sugars and can be used to produce furfural (nodes and sheaths yield 6.6 percent, and the underground parts over 13 percent), which is important for making compressed fiberboard for house construction. *Phragmites* marshes can assimilate waste effluent, and the plant is important as a new method for treating sewage and wastewater (see Chapter 13).

Cattail

Cattails are weeds that present serious problems. Fast growing, they invade new waterways and must be rigorously controlled. They invade rice fields, other irrigated agricultural lands, farm ponds, lakes, and canals. The Aztecs used them as man-made islands in Mexican lakes and swamps. (The stems were cut and arranged to form huge carpets over the mud and soil heaped on top to form a garden.)

Botanically, cattails are species of *Typha*, and several species differing little in physical characters are found in fresh and brackish shallow waters all over the world. Of all wild plants, cattails have been called the most useful emergency food source, and traditionally they have been important foods to native peoples. The rootlike rhizomes contain a firm core that is eaten raw, roasted, or boiled. It is pungent, fibrous, and rich in an edible starch, which can be separated from the fiber as a flour. It is said to contain as much protein as corn or rice and more carbohydrate than potato; one hectare of cattails can yield over 7,000 kg of rhizomes. In times of food scarcity, several nations have considered cattail rhizomes a source of starch and the seeds a source of edible oil and animal feed. Young cattail stems can be eaten in salads or as a green vegetable; even the yellow pollen is edible.

Perhaps the cattail's greatest economic potential, however, is as a source of pulp, paper, and fiber. It can probably be cultivated as a fiber crop on wastelands too wet for other purposes. Little is known of its pulping characteristics or the quality of its pulp, but cattail stems and leaves seem suitable for paper-making. A set of books published in 1765 containing pages of cattail paper is still extant; in 1853, considerable amounts of cattail paper were made in New York. Cattail paper is fairly strong but difficult to bleach. Bleaching would not be essential, however, for production of wrapping paper, our supply of which is diminishing due to a shortage of raw materials. Cattail leaves yield a soft fiber that has been used in mats, baskets, chair seats, and other woven articles. Because they swell when wet, the leaves are reportedly good for caulking cracks in houses, barrels, and boats. A sample of the fiber was displayed at the Amsterdam Exposition in 1876. At that time a French company was formed to manufacture textiles from it. There was much enthusiasm for cattail leaf fiber in Germany and in Romania during World War I and in Russia in the early 1950s.

In 1948, French scientists developed methods for harvesting cattail leaves but all were too expensive. Today, however, with an anticipated scarcity of wood pulp, research to reduce the cost of harvesting cattails seems warranted. There are British patents on chemical and mechanical means of extracting cattail fiber, and a German patent on a mechanical process. Stems and leaves together can be chemically treated with sodium hydroxide to obtain fibers 2-4 m long, closely resembling jute. The yield of fiber is 30-40 percent and one species, *Typha glauca*, can produce 7-10 tons per hectare annually.

Recent studies in Mexico show that woven cattail leaves coated with plastic resins have potential as place mats, building siding, and roof tiles. The resulting product is said to be at least as strong as fiberglass.* The cattail plant will absorb nutrients from wastewaters (see Chapter 13), and cattail stands could serve for effluent disposal while providing a source of cellulose pulp for industry.

Papyrus

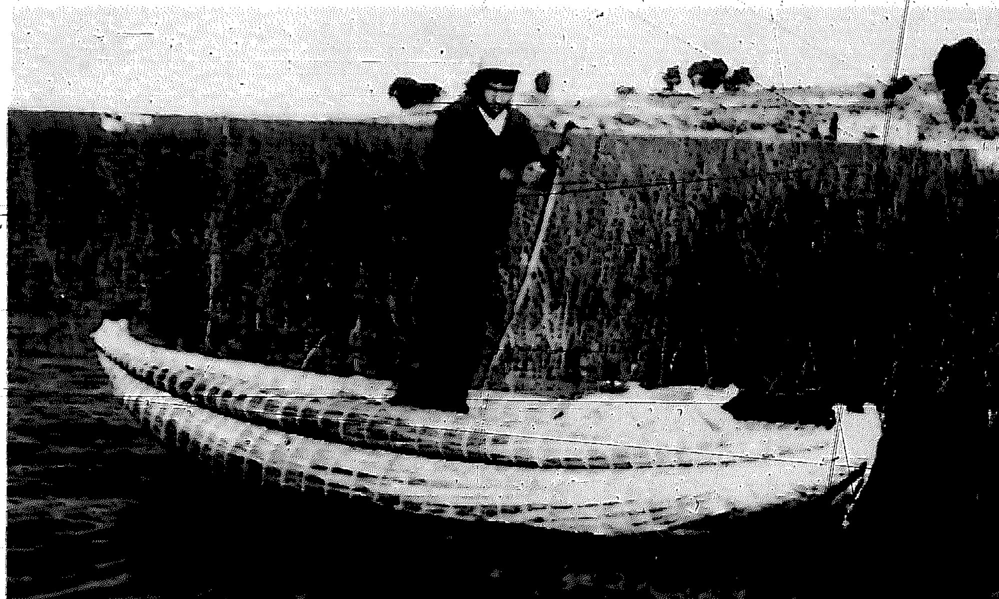
The papyrus reeds *Cyperus papyrus* and *Cyperus antiquorum* form vast stands in swamps, in shallow lakes, and along stream banks throughout Africa. Cultivated in ancient times in the Egyptian Nile delta, papyrus gave its name to the writing material, paper, made from its stem. In use by 3500 B.C., fragments of papyrus sheets dated 4,600 years ago have been found. Papyrus documents have greatly contributed to our understanding of classical literature, ancient religion, and the origins of Christianity and Judaism.

In order to make their writing material, the ancients stripped the fibrous coverings off papyrus stem, and slit the inner pith into waferlike strips. Laid side by side, with others placed crosswise on top, the strips were dampened, pressed so the gluelike sap cemented them together, and dried into a sheet.

From the outer fibrous parts of the papyrus stem the Egyptians made ropes and baskets, wove nets and canvas for boat sails, mats, and furniture coverings; the roots were used as fuel, and the pith made into food.

The administration of the Roman Empire depended on papyrus the way bureaucracies today depend on paper. Paper (a matted sheet of fibers formed on a wire screen from a water suspension) came into use in Europe only 600 years ago, but it took the name of the half-forgotten papyrus.

*Information supplied by Secretaría de Recursos Hidráulicos, Reforma 107 2°Piso, Mexico, 4 D.F., Mexico.



Traditional boat made of reeds, Bolivia. (International Center for Aquaculture, Auburn University)

Today the papyrus plant is considered a scourge, something to be destroyed. In some African waters (for example Lake Victoria, the White Nile, the Congo, and the Okavango swamp) large clumps detach from the land and form floating islands that juggernaut around, obstructing navigation and water flow. Kisumu Harbour on Lake Victoria, Kenya, is constantly plagued with floating papyrus islands. (See p. 7.)

Harvesting papyrus for commercial use is seldom, if ever, seriously considered today. Yet, with a growing world shortage of pulp and paper, research could perhaps turn back the clock and make papyrus a valuable resource for Africa once more. Uganda, for example, has about 6,500 km^2 of permanent swamp, much of it covered in papyrus. The potential economic exploitation of this ecosystem has generated much controversy with some proposing to drain it and raise cattle or pond fish; and others proposing to leave it in its natural condition and crop the fish and papyrus that grow there naturally.

Today, however, there are many difficulties to be overcome before use of papyrus will be economical.* Harvesting is a problem and is expensive, the pulp yield is low, and to make paper, the pith (which makes up much of the stem) has to be removed. The pith contributes no strength to the paper, yet it uses up pulping chemicals and makes the washing and forming of the paper

*These are detailed in a generally pessimistic report by B. Steenberg. (See Selected Readings.).

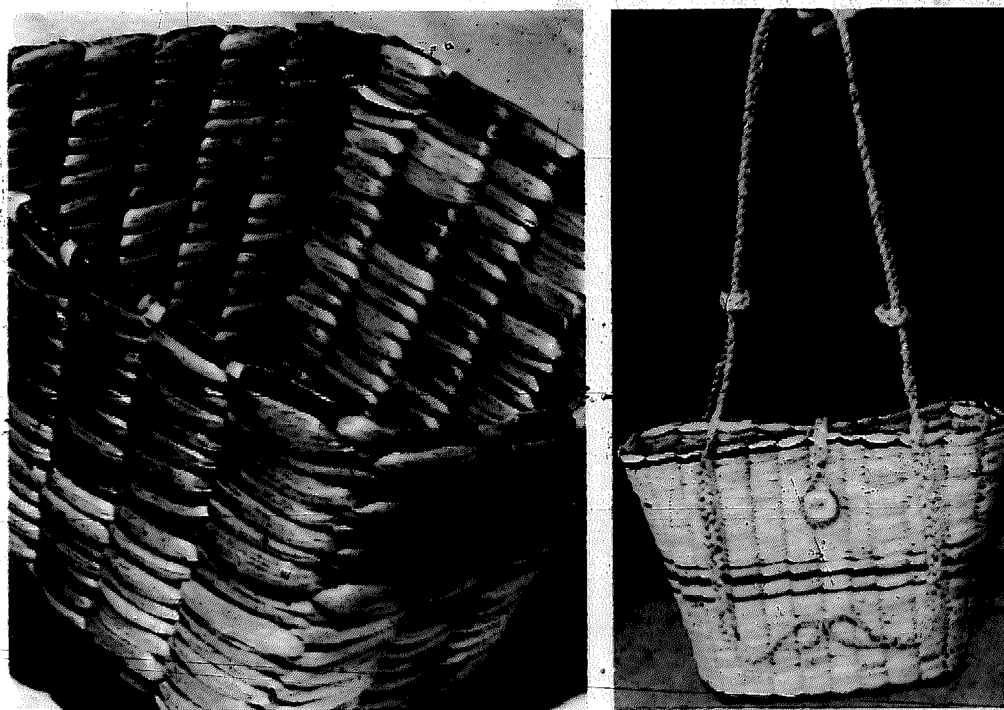
In the Philippines water hyacinth petioles (leaf stalks) are woven into baskets and purses. The leaf blade (lamina) is cut off and the stem hung up to dry. . . .

difficult. Depithing is therefore a key technical problem in papyrus utilization. On the other hand, the pith is not a problem in making hardboard and, because it is rich in hemicellulose, may have commercial value itself.

Though shorter than those of softwoods, papyrus fibers are about the same length as eucalyptus wood fibers, which are used in papermaking in Australia. The pulp can be used as the main constituent in writing and printing papers but not for wrapping papers because of its low strength. The major pulping chemicals all successfully pulp papyrus, and because the stems have no nodes (unlike straw, bamboo, or reeds), the pulp is free of hard particles. Even rayon-grade pulp has been produced. The pulp can be bleached using conditions like those used with rice straw.

Other Aquatic Weeds

Water hyacinth has often been proposed as a source of pulp and paper, and some successes have indeed been reported. However, at the University of Florida, exhaustive attempts to make paper using many different pulping



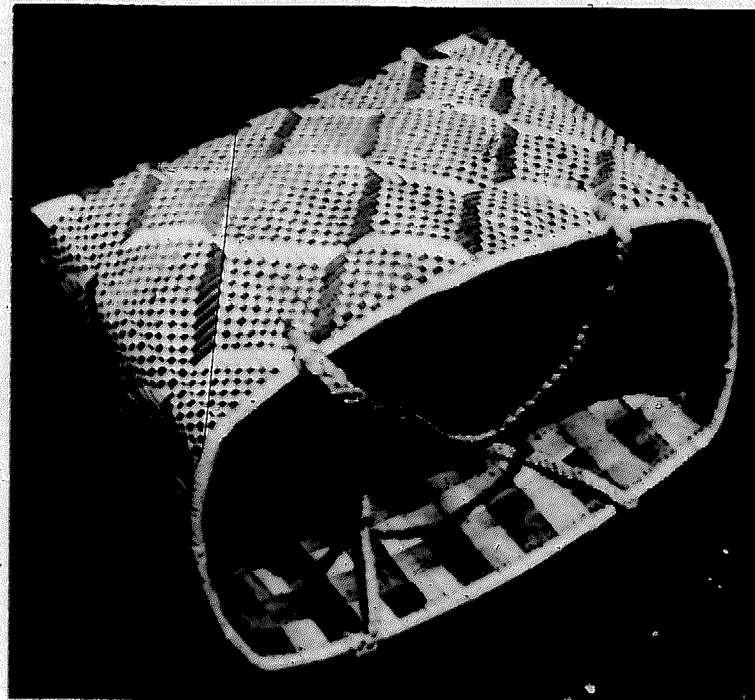
. . . The dried petioles make tough, resilient products that are soft to the touch. Though production has begun only recently, the demand is now outpacing the supply of hyacinth. (Information supplied by Department of Home Economics, Visayas State College of Agriculture, Baybay, Leyte, Philippines.) (D. L. Plucknett and N. D. Vietmeyer)

conditions, have failed.* Moisture clings to the fiber and the pulp cannot be drained or dewatered by the usual papermaking rollers. Water hyacinth does not therefore look promising as an immediate source of pulp.

Mat rush, or "soft rush" (*Juncus effusus*) flourishes in shallow pools and marshes of warm-temperate and subtropical climates. It has long been a wetland crop in Taiwan, China, Korea, and Japan. It is known to have been grown in Japan as early as the 19th century A.D. In 1970, the Japanese harvest amounted to 120 million kg of the dried stems, which are used for floor matting.

The textile screwpine *Pandanus tectorius* forms dense thickets on the borders of lagoons and rivers in Southeast Asia and the Pacific Islands. Clumps occasionally break off and float to other shores. The leaves are used for weaving mats, sacks, hats, and baskets. These products, easily cleaned by washing in the sea, are exceptionally durable (often they are handed down through several generations) and when exported, provide a good source of revenue for the people of Oceania.

*Information supplied by W. J. Nolan.



A beautiful basket made of fiber from the "textile" *Pandanus*, an aquatic plant of the Pacific Islands. Baskets like this are being exported from Niue Island to the United States and other countries. (J. Morton)

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12 Energy

Water hyacinth might one day provide a new source of energy.* In a pioneering effort of great significance, researchers at the National Aeronautics and Space Administration (NASA) are working on converting water hyacinth and other aquatic weeds into a biogas rich in methane. Methane is the main ingredient in natural gas, which is used worldwide as fuel and is a major item in international trade.

The recovery of fuel from aquatic weeds, even if on a small scale, has interesting implications, especially for rural areas in developing countries. As many developing nations have an apparently inexhaustible supply of aquatic weeds within their borders, this potential energy source deserves further research and testing.

Aquatic weeds are converted to biogas by capitalizing upon one of nature's processes for decomposing wastes—decay by anaerobic bacteria. Methane-producing bacteria are common in nature (for instance, in the stagnant bottom mud of swamps, where they produce bubbles of methane known as "marsh gas"). If they are cultured on water hyacinth in a tank, sealed to keep out all air, they produce a biogas composed of about 70 percent methane and 30 percent carbon dioxide.†

The high moisture content of aquatic weeds is an advantage in this process: It is needed for fermentation. This is one method of aquatic weed utilization that does not require dewatering (see Chapter 8)—a big advantage.

Based on NASA's findings it appears that the water hyacinth harvested from one hectare will produce more than 70,000 m^3 of biogas. Each kilogram of water hyacinth (dry-weight basis) yields about 370 liters of biogas with an average methane content of 69 percent and a calorific (heating) value, when used as a fuel, of about 22,000 kJ/m^3 (580 Btu/ft^3). In contrast, pure methane has a calorific value of 33,300 kJ/m^3 (895 Btu/ft^3).

The biogas burns readily. It can be used for virtually every application where natural gas is used: for cooking, heating, and as a source of power. In a limited way, it has even been used to power stationary engines, tractors, and cars. However, before the gas can be compressed into cylinders for use on

*The production of hydrogen (a potential energy source) by the water fern *Azolla* is discussed on page 144.

†For more detail on biogas see the companion volume to this one: National Academy of Sciences. In preparation. (See Selected Readings.)

equipment, the carbon dioxide must be removed, and—unless production is large—it may not be practical to use biogas as a fuel for engines.

Although anaerobic digestion has been used for about 70 years to transform sludges in sewage treatment plants, it is attracting increased attention and research activity today. Several thousand digesters (air-tight tanks that permit the growth of anaerobic bacteria) are in operation around the world, notably in India, China, Taiwan, and Korea. These, however, process animal manure or human wastes mixed with vegetable waste. It is little known that, without any animal manure, aquatic weeds can be digested to methane.

Methane-producing bacteria must be nurtured; they require such nutrients as nitrogen, potassium, and phosphorus. The work at NASA has shown that water hyacinths provide these elements in the quantities and proportions adequate for good growth of the bacteria and for good gas production.

The production of biogas removes carbon from the ferment, but there is little loss of the other elements. These remain as a liquid sludge that is itself an organic fertilizer and soil conditioner equivalent to compost (see Chapter 9). As the need worldwide for fertilizer and the costs of inorganic fertilizers increase, this becomes an important additional advantage.

Limitations

Fermenting aquatic weeds to methane may be accomplished without dewatering, but the weeds usually have to be chopped or crushed to make them more available for bacterial attack. Although simple, cheap equipment can be used for fermentation chambers, they must be constructed and maintained with care. Methane-producing bacteria cannot survive if oxygen is present in the culture medium, and the air that is introduced when the chamber is loaded with weeds results in a lag before anaerobic digestion can begin. During this lag, which can be up to 10 days, the oxygen is used up by aerobic bacteria, which produce carbon dioxide, not methane. With the oxygen gone anaerobic bacteria take over, but biogas always contains a substantial amount of carbon dioxide, a nonflammable gas that dilutes the heating value of the methane.

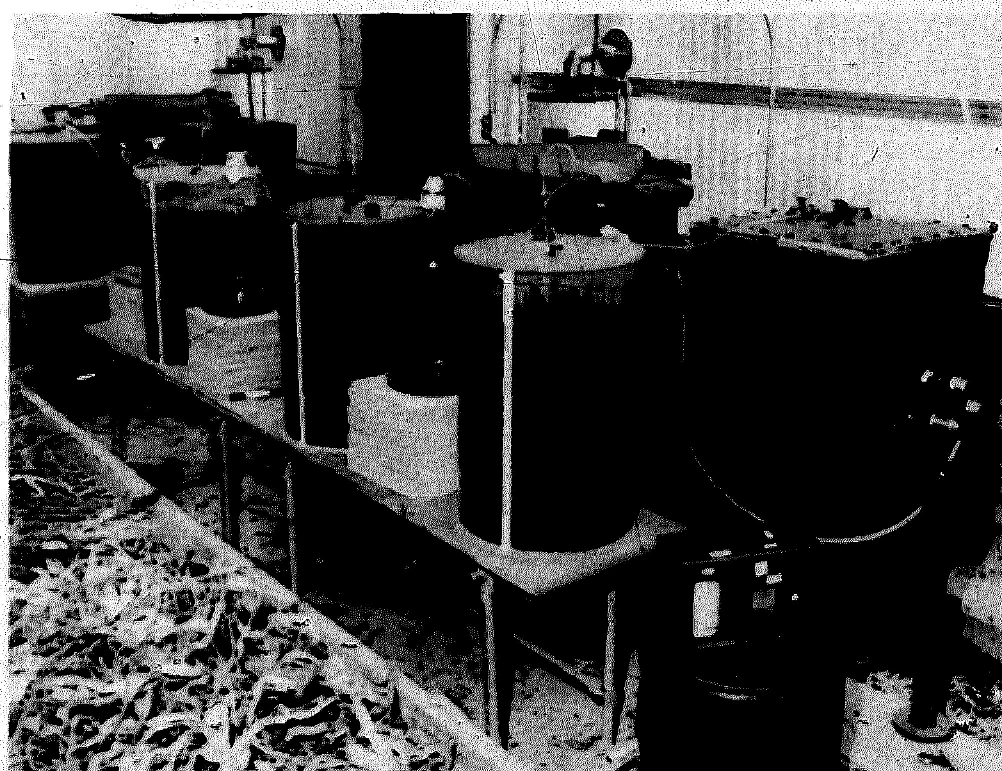
Biogas production is not fast. The bacteria must be given time; 10–60 days may be needed. Furthermore, the initial start-up is slow because the bacteria take time to build up a population big enough to ferment the weeds.

Experience with existing biogas generators (using a medium of animal, human, and vegetable wastes) has shown that the bacteria are sensitive and easily "upset." It takes skill and continual supervision to maintain methane production. The following factors must be considered:

Temperature: Maximum production occurs at 32-36°C. In temperate regions some heating may be needed, but generally in climates that foster aquatic weed growth the optimum temperatures can be reached, especially if the digester is in the sun. The temperature must be kept relatively constant—large fluctuations can distress the bacteria.

Nutrients: The feedstock must contain adequate nitrogen for bacterial growth. The relative amount of carbon present should not exceed 30 times the amount of nitrogen. Carbon to nitrogen ratios between 20:1 and 30:1 are best. Luckily most aquatic weeds are in this range.

Mixing: For maximum gas production, the ferment must be stirred or agitated at least twice daily to break up surface scum.



Experiments for converting water hyacinth ~~(foreground left) into fuel. In the sealed~~ metal tanks the hyacinth is fermented anaerobically (i.e., air is excluded). Small amounts of stagnant bottom-mud from a neighboring pond infested with water hyacinth "seed" the fermentation with methane-producing bacteria. These then convert the water hyacinth into a gas rich in methane—the major ingredient in natural gas, a fuel widely used for cooking, heating, electricity generation, and industrial process. In these experiments the gas is collected and measured in the glass tanks and bottles. It is estimated that the amount of water hyacinth that can be grown on 1 ha of water can be converted to 70,000 m^3 of methane gas; currently worth about $5,000 in the United States. (National Space Technology Laboratories)

Acidity: During digestion, acids can accumulate and suppress the bacteria; sometimes lime or other alkali may be needed to neutralize them.

Biogas must be handled carefully: Methane mixed with air is explosive.

So far there have been no assessments of economic feasibility of using aquatic weeds in a biogas generator that are relevant to developing country situations.

Research Needs

The conversion of aquatic weeds to biogas has been tried in only a few laboratories. It is new and largely untested under conditions usually encountered in developing countries, but the results are potentially so important that process engineers should test out the system in weed-infested developing countries worldwide. Some particularly relevant locations appear to be the People's Republic of China, the Republic of China, the Philippines, Thailand, Malaysia, Bangladesh, India, Sri Lanka, Sudan, Zaire, Zambia, Guyana, Panama, and Mexico. India, in particular, is a promising test location for not only does it have aquatic weed infestations, but Indian engineers are among the most experienced at designing and testing biogas generators.

Plants such as duckweed, water milfoil, hydrilla, alligator weed, and algae have shown initial promise as feedstocks for methane-producing bacteria, but research still needs to be done to learn their true value.

Much research is needed to reduce the fermentation time and to optimize yields.

It is recommended that engineers design a small-sized water hyacinth digester specifically for widespread use in developing countries. Such a design should

- use a maximum of materials indigenous to developing countries;
- require only simple maintenance;
- be cheap and easily constructed;
- be safe and foolproof to operate.

Methods and equipment for collecting, storing, and handling biogas in developing country situations are also needed.

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Research Contacts

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Many organizations in developing countries are experimenting with methane generators that use human, animal, and vegetable wastes. Check with your local university or agriculture department to obtain local information.

Part III

Other Uses

13 Wastewater Treatment Using Aquatic Weeds

Raw sewage contains complex organic and inorganic materials, including proteins, urea, amines, cellulose, fats, carbohydrates, and soaps. In biological sewage treatment facilities bacteria, fungi, zooplankton, and algae degrade and use these complex materials, resulting in an effluent rich in nitrogen, potassium, phosphorus, and other elements. The treated waste has usually been discharged into the nearest lake or river with little thought of the consequences; today, however, the growing world population and an increasing demand for an improved environment make better disposal mandatory.

Recently, researchers have discovered that some aquatic weeds can scavenge inorganic, and some organic, compounds from water. The weeds absorb and incorporate the dissolved materials into their own structure. Effluent renovated by the plants is stripped of its pollutants and, when released into waterways, causes less environmental damage. The plant culture units clean water so rapidly and effectively that they are now seriously being considered for use as a "final polish" in sewage treatment. The clean water produced is, in most situations, suitable for re-use in irrigation and industry. (See a companion NAS report *More Water for Arid Lands*, cited on page 172.) Furthermore, the plants themselves can be harvested and used, thus providing additional benefit. The technique can also be used for treating animal manure and other farm wastes.

For developing countries this could become extremely important. Nitrates, ammonium compounds, phosphates, and organic carbon—discharged from sewage treatment facilities—are nutrients often needed in agriculture. The first two are the primary ingredients in fertilizer, which today costs developing countries increasing amounts of precious foreign exchange to import. Fertilizer manufacture is energy intensive and thus increasingly expensive. For many rural farmers, the price of the foreign product is prohibitive. Aquatic plants promise to provide an indigenous source of cheap fertilizer and soil conditioner available within the rural regions that need it most.

This fertilizer recovery method is simple to carry out: Wastewater effluent is led to shallow ponds planted with aquatic weeds. The resultant crop can be harvested regularly, each time leaving some plants to regrow a new crop so that the water purification becomes a continual process. Alternatively, the plants may be allowed to grow for an entire season and then harvested—perhaps even after draining the pond. This method is versatile and can be scaled for village, farm, or small municipality. It can be used to treat raw sewage or raw farm wastes but they should first be lagooned or diluted.* Wastes from households and food processing (sugar, pineapple, citrus, potato, fish, etc.) can be purified by this process too.

In addition, aquatic weeds can be used to partially strip traces of potentially harmful, or odorous, agents from drinking water including cadmium, nickel, mercury, phenol, and potential carcinogens. The aquatic plants remove and concentrate these elements, which may become 4,000-20,000 times more concentrated in the plants than in the water. One research effort is now under way to see if aquatic plants can profitably recover silver, gold, and other precious metals from ore-refining wastewaters.

An aquatic weed water-treatment system can be inexpensive to build and maintain and, if it is situated so that gravity delivers the wastewater, has virtually no energy costs other than for planting and harvesting the weeds. In a sense the plants are an agricultural crop utilizing solar energy and growing on the nutrients in the wastewater. The harvested plants can be used as described elsewhere in this report to feed herbivorous fish, waterfowl, cattle, and swine (and perhaps goats and rabbits, too), or to provide raw material for making processed animal feed, soil additives, methane gas, and other products.

Not all aquatic plants are equally adapted for growing on wastewaters. Many of those that seem to grow best are common weeds, for example, the common reed *Phragmites communis*, bulrush *Scirpus lacustris*, water hyacinth, duckweeds (*Lemna* spp. and *Spirodela* spp.), forms of elodea (*Elodea canadensis*, etc.), *Egeria densa*, hydrilla, and *Ceratophyllum demersum*.

Methods

Water Hyacinth Method

The vigor that makes it one of the world's worst weeds appears to make the water hyacinth ideal for water treatment. Several research groups in the United States have selected it for study. For example, water hyacinth already is being "farmed" on a 3.6-ha sewage lagoon serving the city of Lucedale, Mississippi (population 2,500) by the National Space Technology Labora-

*See: Callaway, T., and B. Wagner. 1966 (Reprinted 1970). *Sewage Lagoons for Developing Countries*. Department of Housing and Urban Development (Washington, D.C. 20410, USA) Ideas and Methods Exchange #62. 35 pp.

A water hyacinth farm. In Mississippi, USA, sewage from the city of Lucedale is lagooned and then pumped into a series of channels (shown here). The subtropical climate and rich nutrients in the wastewater produce huge crops of water hyacinth biomass. Designed to help the water hyacinth extract the maximum quantities of nutrients, the 1-m deep channels also facilitate harvest of the plants. Once harvested, the vegetation is processed into animal feed (see Chapter 10), fuel, and fertilizer (see Chapter 12). (National Space Technology Laboratories)

tories (a U.S. government facility operated by NASA). The University of Florida and the Texas State Department of Health Resources are also treating sewage with water hyacinth on an experimental basis. During warm weather in these subtropical southern states, water hyacinth can increase at a phenomenal rate of 15 percent surface area per day. At this rate 20–40 tons of wet water hyacinth could be harvested per hectare per day, removing the nitrogenous waste of over 2,000 people and the phosphorous waste of over 800 people.*

Under ideal conditions water hyacinth has recovered the following elements:

Element	Amount Recovered kg/ha/day)
Nitrogen	22–44
Phosphorus	8–17
Potassium	22–44
Calcium	11–22
Magnesium	2–4
Sodium	18–34

*Information supplied by B. C. Wolverton.

Water hyacinth has doubled in area every 6–7 days during the growing season in Florida (March–November). When sewage was passed through a pond at a rate of 2.2 million liters per ha per day (200,000 gallons per acre per day)* water hyacinth growing in the pond removed 80 percent of the nitrogenous compounds and 40 percent of the phosphorous compounds in 2 days.

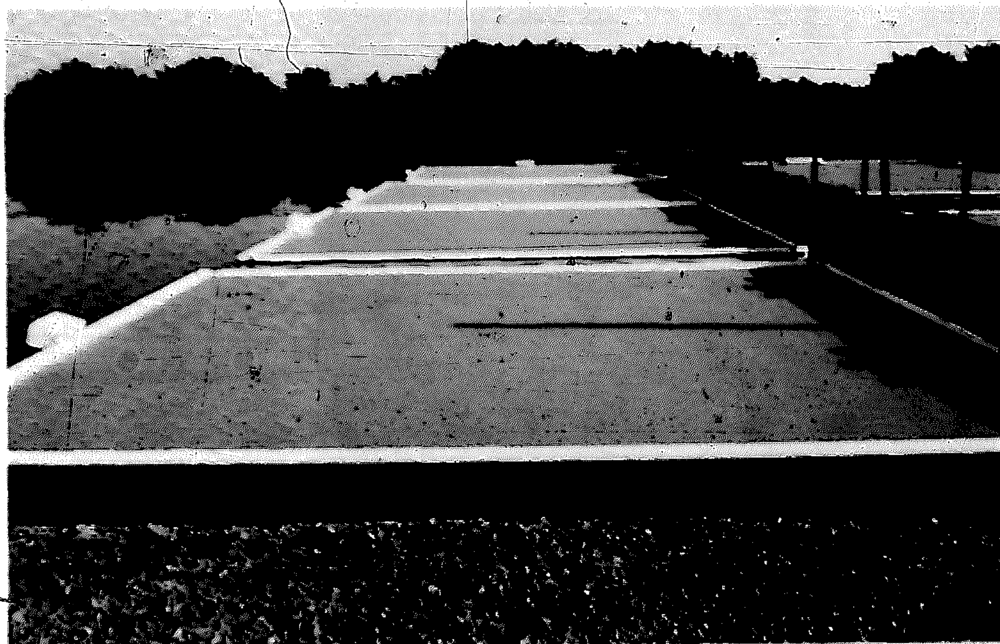
Water hyacinth culture removes algae and fecal bacteria, greatly reduces suspended matter, and removes odor-causing compounds. Reportedly, the resultant effluent is clear, odorless, and contains little nitrogen; some phosphorus remains because it is removed more slowly than nitrogen. Part of the improvement in water quality is caused only indirectly by the water hyacinth: The floating vegetation fosters growth of organisms, such as *Daphnia* (a zooplankton), that feed on bacteria; and it shades the lagoon and reduces wind and wave action, thus helping suspended matter to settle out.

Emergent Plant Method

The Max Planck Institüt of West Germany has developed and patented a water treatment process that uses reeds and bulrushes to purify the water. The untreated wastewater first passes through a bed of gravel topped with sand in which common reed is planted. The reeds quickly grow to be 2–4 m tall and spread their roots through the gravel. Wastewater is spread over the surface of the bed, and solid particles are trapped on the sand as the water percolates downward. Dissolved organic and inorganic material is absorbed by the reeds or decomposed by the microorganisms in the gravel. Since leaves, stems, and roots of the common reed have air passages in them, oxygen is transported down through the plants and outward from the roots to the soil to supply the massive needs of the microorganisms. By creating a route for rapid transport of oxygen to deep portions of the bed, the plants increase the efficiency of the breakdown of organic material. As sludge accumulates on the surface of the bed, the reeds put out new roots from along the base of the stem. These roots aid in digesting the sludge and slow the rate of sludge build-up on the surface of the bed.

The water then flows to the site of the second stage of the process, a gently sloping bed of gravel planted with the bulrush (*Scirpus lacustris*). As the water percolates across this living filter, the plant absorbs more organic materials and inorganic nutrients. Colloidal substances in the water flocculate and settle out as a result. In the presence of the bulrush, bacteria and other pathogens in the sewage are significantly reduced.

*Information supplied by T. deS. Furman.



In Florida duckweed (*Lemna* spp.) is grown on a sewage lagoon. Floating barriers (lengths of plastic pipe sealed at the ends) are used to stop the wind from dispersing the plants. A simple net is used to harvest the plants; about half the area within the barriers is left unharvested each time. The plants grow back to fill the 37-m^2 area within two days. Yields have averaged the equivalent of over 1,200 kg/ha/day or over 60 kg of dry matter per hectare per day. Grass carp (see Chapter 1) grown in these lagoons to feed on the duckweed have produced 1 kg of fish flesh for every 2 kg of weeds consumed. The potential for raising herbivorous animals on aquatic plants in wastewater lagoons is very great. (D. L. Sutton)

A similar system developed in the Netherlands also uses long ditches, largely because they can be maintained mechanically. In this system, however, no gravel is used, and the plants are rooted in the bottom soil. The water flowing through the pond is purified by microorganisms; the nutrients dissolved in the wastewater are absorbed by the plants and by the microorganisms. It is believed that the plants function mainly by providing attachment sites for the microorganisms that purify the sewage.

Under Dutch conditions, the initial investment and the annual operating costs for using their aquatic plant method are reported to be only a sixth and a fourth of the equivalent costs for an activated sludge plant with the same capacity.*

*de Jong, 1975. (See Selected Readings.)

The water leaving these units is clear, neutral (about pH 7), and will not exert an oxygen demand on the receiving waters, though it may contain dissolved nitrogen and phosphorus. The reeds and bulrushes are harvested periodically. The fiber of these plants is valuable (see Chapter 11).

Submerged Plant Method

Submerged aquatic weeds can extract nutrients from wastewater as well as floating and emergent plants, but these plants grow well only in oxygenated water and therefore cannot be used to treat wastewaters where microbial decomposition can create anoxic conditions. Instead, they are best used after the organic wastes have been decomposed to soluble inorganic materials. At this stage pathogens, parasites, and toxic substances have been removed and a variety of herbivorous aquatic animals are able to live. The grass carp (Chapter 1), various herbivorous fishes (Chapter 2), the crayfish (Chapter 4), and waterfowl (Chapter 5) are examples. To these animals, the submerged weeds are a succulent food that they convert into meat more efficiently than more fibrous plants like water hyacinth and reeds. Large-scale experiments in Santee, California, have demonstrated that fish harvested from such ponds are safe for human consumption.*

Because they grow underwater, submerged weeds are difficult to harvest mechanically; herbivorous animals act as harvesters, but stocking rates have to be carefully balanced to avoid decimating the weeds and reducing their nutrient-removing ability.

Two submerged weeds of tropical and subtropical regions that grow well in heavily fertilized water are hydrilla and *Ceratophyllum demersum*.

Duckweed Method

Like the water hyacinth, duckweeds float on water and extract nutrients from it. Species of *Wolffia*, *Spirodela*, and *Lemna* show promise for purifying water. Smaller than water hyacinth, they are easily skimmed from, or floated off, the water surface. They contain less fiber than water hyacinth and are readily consumed by herbivorous fish, poultry, ducks, geese, and other waterfowl. They may also make good ruminant and pig feed, though, like water hyacinth, they have very high moisture contents.

At the Louisiana State University duckweeds are now being grown on dairy farm wastewater. The harvested duckweeds (*Spirodela* spp.) are then substituted for alfalfa in dairy and swine rations. They have the same amount

*Merrell, et al. 1967. (See Selected Readings.)

of protein (the most expensive ingredient in animal feed) as soybeans. (Duckweeds are discussed in further detail in Appendix A.)

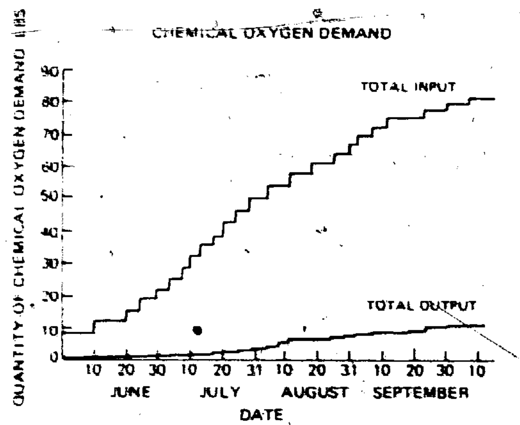
Limitations

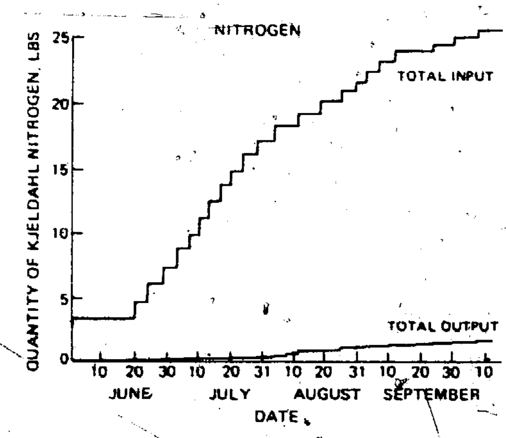
The use of aquatic weeds for wastewater treatment is still experimental. Except for the emergent plant method, the techniques require shallow ponds in which to grow the weeds; in some locations land for such a purpose may be prohibitively expensive. Lagooning wastewaters is not universally accepted as safe for public health; however, lagoons have been used traditionally in Asia and modern research has shown that, if carefully managed, they are safe and perhaps more effective than conventional wastewater treatment for removing pathogenic bacteria, parasitic-worm eggs, protozoa cysts and eggs, and heavy metals. On the other hand, if mismanaged, the lagoons can become odorous and mosquito-filled; they can seep and pollute groundwaters, and can fail to kill pathogenic bacteria.

In using such sewage treatment techniques, there is potential hazard from pathogens, toxic heavy metals, and carcinogens. Care, quality control, and public health safety measures must be enforced. The role of aquatic weeds is to remove inorganic nutrients from *treated* wastewaters; they should not be harvested and used if they have come in direct contact with raw sewage.

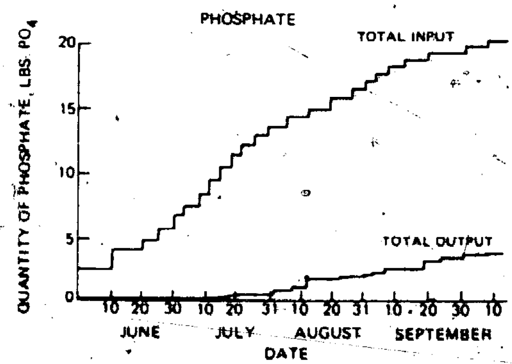
If used where wastewaters contain pesticides, heavy metals, or industrial wastes, the plants must be disposed of safely. In the NASA wastewater

In Tan Chau, a rural area of Vietnam, barns are built so the manure from the sheep and goats inside falls into a pond to fertilize a crop of aquatic plants. Harvested regularly, the plants provide feed for the animals. Simple systems like this that harness aquatic weeds to recycle nutrients are common in Southeast Asia. (H. Popenoe)





Results from a test of using water hyacinth to purify wastewater from a pig farm. The upper lines show the chemical oxygen demand (COD), the total nitrogen, and the phosphate (PO_4) added to the pools in which the water hyacinth was growing. The lower lines show the amount of each pollutant remaining in the water as it left the pools. In these experiments water hyacinth stripped 78 percent of the nitrogen and 72 percent of the phosphate from the manure-laden wastewater. (Information from J. R. Miner *et al.*, see Selected Readings, Courtesy of American Society of Agricultural Engineers)



treatment project, water hyacinths containing such compounds are fermented to methane gas (see Chapter 12).

To achieve satisfactory recovery of phosphorus and nitrogen, the amounts in the wastewater passing through the pond should not exceed the capacity of the vegetation to absorb the nutrients during the residence time of the water in the pond.

Slight turbulence in the water is necessary for a reasonable rate of nutrient removal; in stationary water, nutrients in the top layers are depleted and plant growth slows. Turbulence also improves the oxygen content and distribution and facilitates the growth of bacteria, zooplankton, and other organisms that help break down organic wastes.

Care must be taken to avoid anaerobic conditions in the weed-filled treatment ponds. For example, a floating weed mat that completely covers the water surface reduces natural aeration of the water as well as the sunlight needed for photosynthesis by algae and submerged plants that also oxygenate the water. By regularly harvesting the weeds and thus maintaining free water surface, or by stocking the plants on *final effluent* from previous water

Wastewater is purified as it percolates through beds of the bulrush *Scirpus lacustris* near Elburg, the Netherlands. (C. D. McNabb)

treatment facilities (that is, saturated with oxygen and free of matter that will absorb it from the water), anaerobic conditions can be avoided.

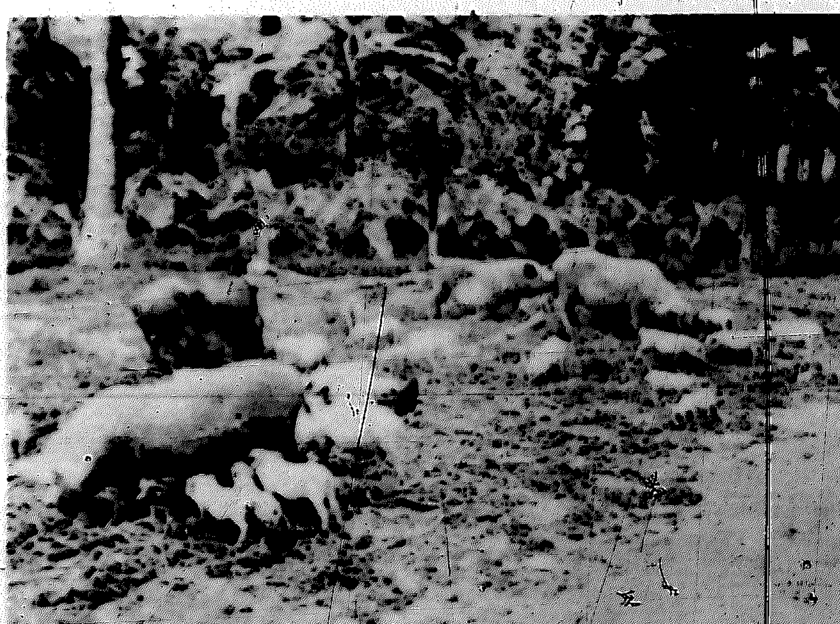
Research Needs

Aquatic weed wastewater treatments could make excellent research projects for biologists and sanitary engineers in developing countries. There is much yet to learn, and the concepts developed elsewhere can be modified to fit local weeds and local needs. The techniques need much ingenuity but do not require complicated technology, great expense, or imported equipment. Aquatic plants appropriate for treating wastewater are already available in most countries—*aquatic weeds should never be introduced to a new country or area. They are among the most pernicious weeds on earth.*

Research is needed to optimize the design and management of the systems to get maximum nutrient recovery year-round. It should deal with the recovery of nutrients that can be used directly as fertilizers, the recovery of energy (as through biogas production), and the production of meat by feeding the weeds to aquatic herbivores or terrestrial animals.

Research is also needed to optimize the design and management of various systems described here to get the maximum energy, fiber, and protein recovery that is possible year-round. It should also deal with developing

The Bayan Lepas Farm near Penang (Malaysia) was organized in the 1950's to combine pig-rearing with fish-farming and vegetable-growing. Heart of this intensive system is the lagoon stocked with herbivorous fish (grass carp [see Chapter 1], tilapia, silver carp, and common carp [see Chapter 2]) and planted with water spinach (see Chapter 14). Though some were eaten by the fish, this aquatic plant grew well and . . .



. . . at peak production the 1-ha pond (1–1.5 m deep) daily yielded 480 kg of water spinach for pig food. All dung and wastes from the pig sties were washed into the lagoon to fertilize and maintain the water spinach crop. (Information taken from S. W. LeMare, see Selected Readings) methods for harvesting, handling, and processing the weeds efficiently and profitably.

Little research has been done on food production systems in which animals can feed directly on the plants in an integrated polyculture. Some animals that should be tried are herbivorous fish (see Chapters 1 and 2), freshwater clams, and ducks, geese, and swans (see Chapter 5). In addition, combinations of these animals with others that live on detritus, zooplankton, molluscs, etc., are also well worth research; in combination they can use all of the foods available in a wastewater lagoon.

It is likely that mosquitoes or other vectors that carry diseases may use the weed-filled lagoons for breeding. In any given area, studies should therefore be conducted to determine the extent of this risk before the system is put into wide-scale use.

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Wolverton, B. C., R. M. Barlow, and R. C. McDonald. 1975. *Application of Vascular Aquatic Plants for Pollution Removal, Energy, and Food Production in a Biological*

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14 Aquatic Plants for Food, Miscellaneous Uses

Many food plants grow in the world's fresh waters, but except for rice, none has been the subject of concentrated research. Though a few aquatic plants are farmed, most are produced in native cultures by traditional methods. Modern technology has seldom been applied to the cultivation of aquatic plants, a grossly neglected area of aquaculture: Fish, shellfish, and crustaceans receive much attention while the production of edible aquatic plants receives virtually none.

In the near future, as burgeoning populations force us to utilize marginal agricultural areas, aquatic plants may be cultivated more intensively. In most parts of the world there are swamplands and shallow ponds totally unsuited to conventional fish culture or agriculture. Man's present policy toward such areas is to drain and "develop" them for uses that are not in accord with their nature – for homes, industry, recreation, or agriculture. There is a pressing need to find techniques that will allow us to use wetlands as wetlands. Cultivating aquatic plants is one possible way. This chapter highlights a few species that, with research, could become more important aquacultural crop plants.

Some of these plants are pernicious weeds. They should never be introduced to new locations or encouraged to spread in old ones. They are included for the benefit of those areas that already have them and would like to see them used productively.

Aquatic plants can provide three types of food: foliage for use as a green vegetable; grain or seeds that provide protein, starch, or oil; and swollen fleshy roots that provide carbohydrate, mainly starch. Examples of all three follow.

Water Spinach (*Ipomoea aquatica*; also known as *I. reptans*)

A tropical trailing herb of muddy stream banks and freshwater ponds and marshes, the water spinach is native to India, Southeast Asia, Taiwan, and southern China, where it is cultivated most. It has been introduced success-

A white-stemmed variety of water spinach (*Ipomoea aquatica*) for sale in a Hong Kong market. (D. A. Griffiths)

Water spinach growing in flooded fields in Hong Kong. (D. A. Griffiths) fully to Fiji, Hawaii, and Florida. Its fresh young leaves and stems are used as a vegetable, boiled or cooked in oil, especially during summer months when other leafy crops do not grow well. It is also used for pickles. It is very popular in Hong Kong and comprises about 15 percent of all the vegetables produced for the local markets. Much is also used as fodder for pigs, cattle, and fish.

Farmers favor water spinach because it is easy to grow, has relatively low labor requirements, and can be harvested irregularly to fit the market. In Hong Kong, the cultivation of water spinach has been perfected and, with heavy fertilization (usually in the form of night soil applied 2–3 times a week), annual yields may be as much as 90,000 kg per ha.

Water spinach seedlings germinate and grow poorly underwater; the seed is usually germinated and grown the first 6 weeks on a dry portion of the field. Then the field is flooded to a depth of 3–5 cm, the soil trampled to liquid mud, and the cuttings planted in it. They root rapidly and require little further attention. No weeding is necessary. As the crop grows, the depth of water is increased to about 15–20 cm. Water control is essential. In order to conserve fertilizer, water flow is halted for 12 hours after fertilizing. Some stems are ready to harvest only 30 days after planting. Ten or more such harvests may be made in a season.

Protein content of the fresh plant varies from 1.9 to 4.6 percent; carbohydrate averages 4.3 percent. It has been estimated that "a 1 ha pond, in a tropical region with a year-round growing season, planted with nothing but this species, could annually produce 770 kg of protein and 1,059 kg of carbohydrates, or considerably more usable food than many commercially profitable fish ponds."* The leaves are good sources of minerals, especially iron, and vitamins A, C, and E.

In Malaysia water spinach has been grown as an aquatic crop for animal feed (see page 95 and illustration page 124).

Watercress (*Nasturtium officinal*; also known as *Radicula nasturtium-aquaticum* and *Rorippa nasturtium-aquaticum*.)

Watercress† is a herb of the mustard family native to Europe and northern Asia. It has also been widely cultivated in temperate and subtropical regions of the world and is grown at cool altitudes in tropical zones. Prized as a fresh-salad herb or as a cooked green vegetable, it is a rich source of iron, iodine, and vitamins A, B, and C. The plant needs cool or cold streams and grows submerged, floating, or spread over mud surfaces. It is usually

*Bardach et al. 1973. (See Selected Readings.)
†Known in Great Britain as "cress."

Harvesting watercress on the Sumida Farm near Honolulu, Hawaii. (USDA Soil Conservation Service, Honolulu, Hawaii)

cultivated in beds flooded with flowing water up to 10 cm deep. These beds can be built adjacent to springs, artesian wells, clear flowing streams, or canals and the water diverted to them in small channels or pipes. Rapid growing, the plants can reach 30 cm high and be ready for harvest in 30-60 days. The tops are cut off below water level and are soon replaced by new growth. Three or four crops are obtained before replanting. In the wild, watercress perpetuates itself year after year.

If the water is polluted, watercress can become contaminated with amoebae and is dangerous to eat raw. Where this is a possibility, the watercress must be washed with disinfectant.

Other Aquatic Plants Grown as Leaf Vegetables

A few, little-known, aquatic plants are reported to be used as green vegetables in small areas of the tropics—they have seldom, if ever, been produced elsewhere.

Neptunia oleracea (also known as *N. prostrata*) is a curious plant with feathery leaves and stems made buoyant by their spongy white covering. It floats on still or slow-flowing fresh waters of southern Asia, Africa, and tropical America and tends to invade irrigation ditches. It is grown in tanks in Thailand and Vietnam, and the fresh plant is sold in markets as a vegetable. The young plants are cooked as greens; the stems are crisp and juicy. Young seedpods, also, are cooked and eaten. There is no available literature on the productivity or food value of this aquatic crop. (It may be rich in protein, for the plant is a legume.)

In Java, young plants of *Limnocharis flava* are a "common and much-esteemed vegetable 'purportedly' not adequately appreciated elsewhere." Favoring wet muddy places and shallow water, it occurs wild from Mexico and the West Indies to Peru and Brazil. Introduced into tropical Asia before 1870, it has become thoroughly naturalized throughout Malaysia. It is cultivated in rice paddies and marketed as a fresh vegetable, especially to provide income if the rice crop is not successful. The young leaves, stems, and flower clusters are cooked and eaten. Old plants are plowed into the rice fields as green manure. The plant is readily grazed by cattle. Young leaves contain 1-1.6 percent protein.

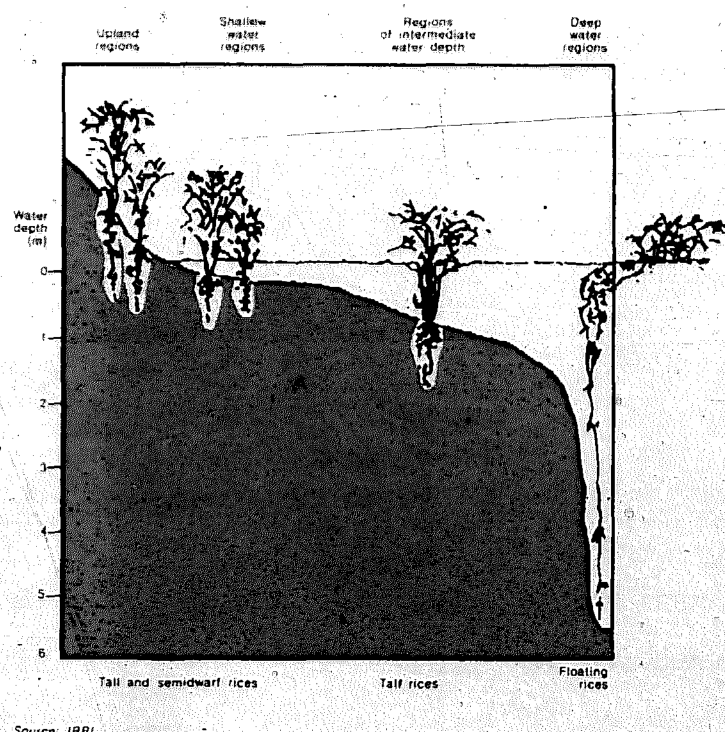
Ceratopteris thalictroides is an aquatic fern that is commonly found wild in swamps, rice paddies, and along ditches throughout much of tropical

Ceratopteris thalictroides purchased in the market, Los Baños, Philippines. This aquatic fern, virtually unknown to science, is a well-known vegetable among villagers in the Philippines. It is almost the only fern in the world that is used for human food. (N. D. Vietmeyer) and subtropical Asia, the East Indies, and Oceania. The new fronds, just uncoiling (fiddleheads), are widely eaten, raw or cooked. The entire plant, except the root, may be cooked as greens. No information is available on its food value.

Ottelia alismoides is a submergent plant, as only its flowers appear above the water. It is common in shallow lakes and slowly moving streams from Australia to Egypt as well as in southern Italy. It invades rice fields and is encouraged in fish ponds to maintain the water quality. The entire plant, except the roots, is gathered and cooked as a vegetable and is said to have excellent flavor. In Thailand the leaves are valued for seasoning rice. No information is available on its food value, which should be investigated.

Floating Rice (*Oryza sativa*)

Floating, or deep-water, rice grows on about 10 percent of the world's rice land. Most is grown by subsistence farmers in the densely populated river



Water too deep for conventional rice often occurs in developing countries. Bangladesh, India (the Gargetic Plain, West Bengal, and Assam), Thailand, Burma, Khmer Republic, Vietnam, Indonesia, Gambia, Sierra Leone, Niger, Nigeria, and Mali already plant large areas of floating rice in areas prone to deep flooding. The International Rice Research Institute (IRRI) has recently announced that "yield breakthroughs are possible in both the floating and medium-deep rice varieties." New lines of floating rice are now being tested in several Asian and African countries. (IRRI) valleys and deltas of Bangladesh, India, Burma, Thailand, the Khmer Republic, Vietnam, Indonesia, and parts of Africa. In these areas the water depth during the growing season can be as much as 6m—too deep for standard rice varieties, particularly the new high-yielding, semi-dwarf ones.

Farmers usually broadcast the seeds in dry or moist soil before the heavy rains begin. As the monsoon rains raise the water levels, the stems rapidly elongate, keeping the leaves above water.

Floating rice is sometimes harvested from boats. In areas where the water recedes before harvest, a tangled mass of stems and curving shoots is left behind. Research on floating rice is still in its infancy, and this rice yields somewhat like unimproved conventional rice varieties.

Though in 1975 the International Rice Research Institute announced that one variety (1442-57) can elongate as flood waters rise by as much as 180 cm, and can produce up to 3 tons per ha in conditions where traditional tall plants are destroyed, nonetheless, varietal improvement has been limited to selection of a few existing varieties. There is an urgent need to identify the factors that limit yields, to screen and classify germ plasm, and to select the most appropriate strains for genetic improvement. There is also an urgent need for better cultural practices.

The plants are often completely submerged for up to 30 days by unpredictable floods in areas where water control is poor. Flood-tolerant varieties that will yield well under such conditions need to be developed.

Farmers in fields of deep water or "floating" rice near the Deep Water Rice Experiment Station, Habiganj, Bangladesh. (International Rice Research Institute)

Harvesting wild rice. (U.S. Department of Agriculture)

Wild Rice (*Zizania aquatica*)

Wild rice is a broad-leaved grass that abounds in marshes, in shallow ponds, and on stream banks of southern Canada and the northwestern United States. For many years the rice-like seeds have been gathered from the wild and marketed at high prices as gourmet food. Only in recent years has wild rice been successfully cultivated. This development may make it possible to introduce it to suitably high elevations in tropical zones.

Wild rice grows naturally in fresh water about 1 m deep and the fruiting stalk may become 3 m tall. In order to avoid crop loss, the heads are traditionally bent over and tied down to the stalks just prior to seed maturity. The seeds mature over 2–3 weeks in late summer and early autumn and drop quickly, so they must be harvested without delay. This is done by beating the heads to make the seeds fall into a boat. Large, self-propelled harvesting machines are used in Canada. After sun drying the seeds for a day, the hulls are loosened by threshing and separated by fanning.

Wild rice is relatively high in vitamin B, and its easy digestibility makes it suitable for individuals with gastric problems. When green, it needs no cooking; boiling water is simply poured over it. Dried, it must be cooked for one hour.

A closely related species (*Zizania caducifolia*, also known as *Zizania latifolia*) is cultivated in Japan, China, and Vietnam.

Lotus (*Nelumbo nucifera*; also known as *Nelumbium speciosum*)

The sweetly scented pink or white lotus flowers have been sacred in India, Sri Lanka, and China since earliest recorded history. In Hinduism, Brahma, the Creator, is visualized as reigning from a lotus flower. In Buddhism, the lotus motif appears in tapestries, statuary, and religious symbols. Ancient Egyptians ate the seeds (carpels) raw and ground them to flour that was made into bread. Today lotus is widely cultivated in the Orient and the seeds and roots (rhizomes) used in a variety of cooked and fresh dishes.

The lotus is grown from rhizome "eyes" or from seed. The rhizomes can be harvested in under 9 months, and yields up to 4,600 kg per ha have been reported. Rhizomes are marketed fresh, dried, canned, or as a fine white starch. They are often cooked in curries and other oriental dishes. Among Chinese populations the world over there is a constant demand for lotus roots. Both dried and canned, the rhizomes sell for high prices. Protein content is about 2.7 percent. The thick, cylindrical roots–60-120 cm long and 5-10 cm in diameter–have longitudinal air channels so that the sliced root looks like Swiss cheese. The seeds are eaten raw, cooked, candied, ground to flour, or canned (after peeling and removing the bitter embryo). In different parts of India the flowering stems and young fruits are also eaten.

The lotus is also cultivated as an ornamental in many countries. It is grown in ponds from India to Japan and in Hawaii. It grows luxuriantly in standing water and in mud. Little land preparation (weeding only) or cultivation is required.

Gathering lotus for food. Stems, seeds, and young leaves are edible. (U.S. Department of Agriculture)

A crop of Chinese water chestnut in the southeastern USA. . . .

Chinese Water Chestnut (*Eleocharis dulcis*; also known as *E. tuberosa*)

Long valued as a vegetable delicacy throughout the Orient, the tuberous root (corm) of the Chinese water chestnut is now an important item in international commerce. It brings high prices in foreign markets and is a common ingredient in chop suey and in Chinese meat and fish dishes.* Firm and white, the tubers retain their crisp, applelike texture even after cooking. In China they are widely eaten like fresh fruit.

The Chinese water chestnut plant (also known as "matai") is cultivated in flooded fields, often in rotation with paddy rice. The water chestnuts are produced in large quantities on underground roots (rhizomes). Small "seed" tubers are first raised in nursery beds then, like rice, transplanted to the field, which is soon flooded and left. Six months later, the field is drained and the tubers harvested; yields can exceed 7 tons per ha. In the People's Republic of China, Taiwan, and Hong Kong many are then peeled, canned, and exported. Like other root crops they are high in carbohydrate (30 percent) and low in protein (1.5 percent).

*The kernels of the spiny fruit of the floating aquatic plants *Trapa bispinosa* and *Trapa natans* (also known as *T. bicornis*) are also sold as water chestnuts. *T. bispinosa* ("singhara nut") is native to, and cultivated slightly in, India. *T. natans* ("ling nut") is cultivated in most of eastern Asia. It has become a pestilential weed in the eastern United States.

. . . The underground corm (tuber), a staple food in the Orient, is said to be as nutritious as a potato, but retains its crunchy texture when cooked. Raw, water chestnuts have a sugarcane and coconut flavor and some food scientists foresee a much greater use of water chestnuts in soups, casseroles, stuffings, and candies. Recently, new processing technology and harvesting machines have been developed that could make water chestnut into a new agricultural crop in the United States and other countries. (W. G. Murray, U. S. Department of Agriculture)

In 1976 the U.S. Department of Agriculture achieved breakthroughs in water chestnut cultivation including the development of new, high-yielding, sweet-tasting strains and of mechanical water chestnut harvesters.*

Taro (*Colocasia esculenta*)

Taro is a tropical crop that is commercially exploited in only a few countries. It can be grown under swampy conditions or in flooded paddies like rice. It produces tuberous roots with a nutty flavor that can be used as a rice or potato substitute. Though a particularly promising crop for aquatic situations, taro receives little research support. Its promise and research needs are detailed in a companion report, *Underexploited Tropical Plants with Promising Economic Value.*†

Swamp Taro (*Cyrtosperma chamissonis*; also known as *C. edule*)

Grown mostly in the South Pacific and in some parts of Indonesia and the Philippines, swamp taro is a tropical root crop that deserves wider recognition

*Information supplied by W. G. Murray, U.S. Department of Agriculture, Agricultural Research Station, Southern Region, P. O. Box 5677, Athens, Georgia 30604 and G. Leeper, R. J. Reynolds Tobacco Co., Winston-Salem, North Carolina 27102.
†National Academy of Sciences. 1975. (See Selected Readings.)

Harvesting giant swamp taro, Pila Laguna, Philippines. This 2½-year-old specimen yielded. . .

. . . an edible root (corms and cormels) weighing 21 kg. An adjacent plant 2 years older yielded 79 kg of edible roots. (D. L. Plucknett) and testing in new locations. It is a hardy plant that grows with little or no care in fresh or brackish swamps and withstands flooded and shaded conditions unsuitable for most other food crops. It produces enormous corms that can weigh over 100 kg. (The largest recorded was from Ponape, Micronesia, weighed 180 kg, and required twelve men to lift it.) Like the tubers of cassava, taro, yams, potato, and other root crops, the swamp taro tuber is fibrous, rich in starch but low in protein (0.7-1.4 percent). It is eaten cooked as a vegetable or made into flour.

Swamp taro is one of the few plants that can grow productively on coral atolls. In the Gilbert Islands, the people dig pits or trenches down to the mud at the freshwater level, set the young plant in the mud, and weave a large basket around it. Into this they pack soil, sand, coconut leaves, animal manure, and almost any organic refuse. The giant corms produced in this man-made mini-swamp can take several years to mature. In the Solomon Islands, the crop is grown in coastal marshes. Some cultivars may mature in 1 or 2 years, but others have an acrid flavor if harvested in less than 2-3 years. Maximum quality and yield (about 10 metric tons per ha) may require a growing period of 5-6 years. The plants do best in slowly moving water less than 1 m deep. Corms can be stored in good condition for one month in cool, dry storage. If scalded, chopped, and sun-dried they can be kept for several months. If eaten raw the corm is acrid and irritating; only after peeling and thorough cooking (boiling or roasting) can it be safely eaten.

Arrowhead (*Sagittaria trifolia*; also known as *S. sinensis*)

These robust emergent aquatic plants, with leaves the shape of arrowheads, produce eight or more underground stems, each with a corm on the end. Each white, or buff-fleshed, corm is roughly the size of a Chinese water chestnut (see page 137). They are boiled and used like potato. In swamps throughout tropical and subtropical Asia *S. trifolia* grows wild or semicultivated, and its corms are a constituent of several Japanese and Chinese meat dishes. The corms also make good pig food.

The composition of arrowhead corms suggests that this crop should be much more widely used than at present. Recent literature records the protein content as 5-7 percent,* more than twice the average value of such other root crops as potatoes, yams, and taro. In 21 countries (including Bangladesh, China, Hong Kong, Korea, Japan, the Philippines, Taiwan, Thailand, and Vietnam) arrowhead is reported as a serious and widespread weed. If exploited, it could contribute to the food supply and nutrition of those countries.

*Kay. 1973. (See Selected Readings.)

Aquatic plants have important esthetic uses. This water garden in Bogor, Indonesia, is beautified by blossoms of *Nymphaea rubra*. (E. S. Ayensu)

Arrowhead grows fast: Seeds or small pieces of corm that are planted in fertile swamps, flooded rice fields, or ponds are ready for harvest 6–7 months later. Arrowhead requires no care or cultivation. Yield information is not available, but the plant is considered prolific.

Escaping into nearby wet areas, arrowhead spreads freely and can quickly become a pest. It should not be introduced to new areas outside its current distribution. *S. sagittifolia*, a species closely related to *S. trifolia*, is found in Europe and parts of the Americas. It also may have potential as a crop.

Azolla Species

Azolla is a genus of small ferns that grow floating on water. The *Azolla* growth rate is large and experiments in India have shown that, during its

The microscopic alga *Anabena azolla*, which grows in the leaves of the water fern *Azolla*, is both a source of fertilizer and of fuel. In nature the alga fixes nitrogen from the atmosphere and makes it available to the *Azolla* in the form of ammonia, a common fertilizer ingredient. Indeed in Asia *Azolla* is often grown in rice paddies as a source of fertilizer. Recently in laboratory studies researchers have found that the alga can be made to produce hydrogen from water. Although still small scale these results suggest that one day the *Azolla/Anabena* symbiosis may be harnessed as a source of hydrogen for fuel. (U.S. Department of Agriculture)

growing season, *Azolla pinnata* can double its weight in less than 7 days.* Although a serious weed in Europe, South Africa, and other areas, *Azolla* has been reported useful for controlling mosquitoes and other weeds (by blocking the water surface) and for feeding poultry, swine, and ducks.

But perhaps *Azolla's* greatest contribution to developing countries can be as a green manure, especially for rice. Farmers in Thai Binh Province, the most intensively cultivated area in northern Vietnam, deliberately cultivate

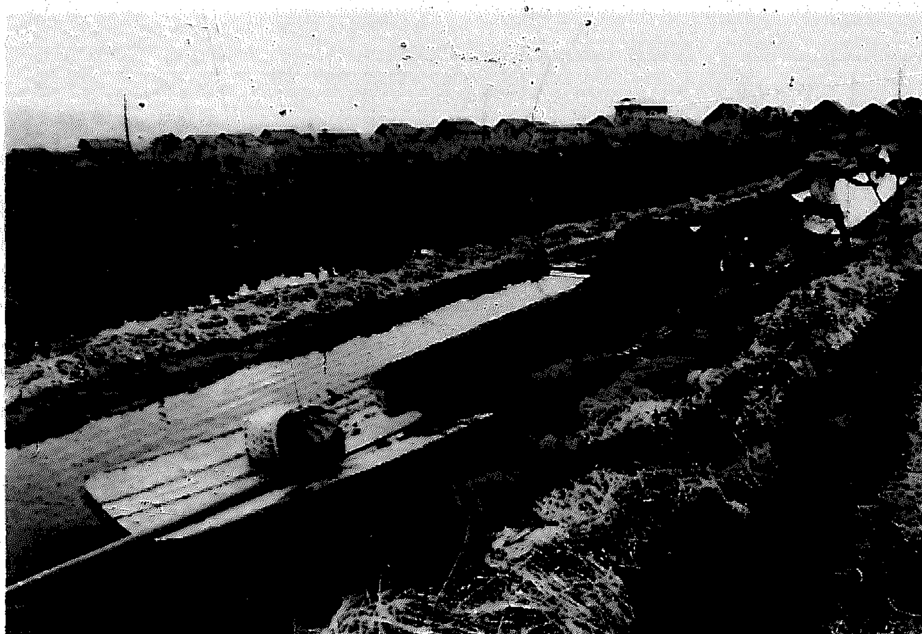
*Gopal. 1967. Contribution of *Azolla pinnata* R.Br. to the productivity of temporary ponds at Varanasi. *Tropical Ecology* 8:126-30.

While advanced countries wage war on hyacinth, peasants in the Far East have learned to turn it to advantage. In the Philippines and Bangladesh observant fishermen noticed that fish are attracted to the fringes of hyacinth beds. So they create their own and rig them with a net to trap the fish. A circle of bamboo stakes seeded with a plant or two is enough. The floating circlets of lush greenery this produces makes a picturesque sight. But they are effective fish traps; crustaceans, small fish, and algae haven among the myriad hairlike roots that hang in the water. These attract edible-sized fish, which the fisherman periodically catches by sweeping his net beneath floating plants. (G. Gerster, Photo Researchers, Inc.)

Azolla pinnata in rice paddies. It is reported that, in these fields, rice yields are 50 percent higher than normal (or more).*

A blue-green alga, *Anabena azolla* lives in cavities in the *Azolla* leaves. It fixes nitrogen from the air and excretes nitrogenous compounds into the leaf cavity from which the *Azolla* can absorb them. The alga provides not only its own nitrogen needs but also those of the *Azolla*, its host. According to one report, the method for capitalizing on this in Southeast Asia is to stock a corner of the rice paddy (at transplanting time) with *Azolla* and to fertilize it with pig manure, straw, ash, etc. The mat of *Azolla* then expands until all the paddy between the growing rice plants is covered with a thick mat of it. In the summer's heat the *Azolla* decays, releasing into the paddy the nitrogen its alga has obtained from the air.

*Galston. 1975 (see Selected Readings.); Sunstov, A. A. 1962 Zemledelic v Demokraticheskoi Respublike Vetnam. (Agriculture in the Democratic Republic of Vietnam). *Zemledelic* (Moscow) 12:74–9.



A vegetable garden floating on aquatic weeds, Inle Lake, Burma. In Burma, Bangladesh, and Kashmir land-poor farmers create floating gardens by scooping bottom muck onto floating mats of aquatic plants. Sometimes the gardens have to be anchored with bamboo poles lest they float to the neighbor's place. . . .

. . . Leaning from canoes, the farmers plant and tend vegetables in floating gardens. The nutrient-laden bottom muck and the surfeit of "irrigation" provide them bumper crops. Floating agriculture of this type was the mainstay of Aztec culture in Mexico before Europeans arrived. (W. E. Garrett [c] National Geographic Society)

Recently it has been discovered* that *Anabena azolla* uses light energy not only to fix nitrogen from air, but also to release hydrogen from water. This is reported to be the first known photosynthetic system for producing hydrogen from water that is stable in air and that requires only water as a hydrogen source. In nature the fixed nitrogen combines with the hydrogen to form ammonia that fertilizes the host *Azolla* fern. But in the laboratory the alga/fern symbiosis can be diverted from producing ammonia to producing hydrogen gas. Although only small-scale experiments have been conducted so far, this is thought to be a promising biological method for producing hydrogen on a large scale. And because hydrogen yields more energy (on a weight basis) than any other nonnuclear fuel, this is a potentially important finding in these days of dwindling petroleum supplies.

Spirulina (*Spirulina platensis* and *S. maxima*)

Although spirulina is a microscopic alga and does not truly fit the selection criterion for this report, it forms large, dense aggregations that can be harvested as if they were higher aquatic plants. Harvested spirulina can be concentrated by draining off the water through a simple bag made of muslin. Sun-dried cakes of spirulina are already used as food in Chad and Mexico. More details of spirulina's promise, limitations, research needs, and literature are given in a companion report, *Underexploited Tropical Plants with Promising Economic Value.*†

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Appendix A
Duckweeds and Their Uses

This report has not detailed individual weed species, but the duckweeds are so ubiquitous, so promising, and so neglected as crop plants that a note on them seems justified. Found in fresh waters worldwide, duckweeds are tiny, fragile, free-floating, aquatic plants. Their vegetative reproduction is rapid, and they cluster in colonies, forming across the water surface a scum that sometimes becomes a minor nuisance in irrigated crops, farm ponds, slow-flowing canals, and small hydroelectric facilities.

Duckweeds belong to four genera: *Lemna, Spirodela, Wolffia* and *Wolffiella*. About 40 species are known. None have distinct stems or leaves but consist instead of flattened, minute, leaflike, more or less oval "fronds" a few millimeters across. Many lack roots, while flowers (rare in many species) are so small as to be nearly invisible to the naked eye.

Among the most vigorously growing plants on earth, some species (e.g., *Spirodela oligorhiza, Spirodela polyrhiza*, and *Lemna minor*) have been known to double their numbers in three days or less. It has been estimated that with its phenomenal reproduction rate, an initial 6.4 cm^2 (1 $in.^2$) of *Lemna minor* would, in 55 days, cover almost half a hectare (1.2 acres).

Duckweeds are collected in vast quantities and used as manure or fodder for cattle and pigs in tropical Africa, India, and Southeast Asia. Recent research results attest to the value of this traditional technique and indicate that duckweeds may have important potential for a variety of uses throughout much of the tropics and subtropics. Although relatively few have yet been made, analyses suggest that the nutritive value (for both animals and humans) of duckweeds exceeds that of most agricultural crops. The protein content is high, and the protein is rich in amino acids that are normally lacking in plant protein. Duckweeds appear promising for use in recovering nutrients from wastewater (see Chapter 13) since their small size makes them easy to harvest and handle. They are attacked by few pests and, when grown on nutrient-laden waters, are more productive than terrestrial agricultural crops.

Human Food

Wolffia arrhiza is the smallest duckweed–indeed it is the smallest flowering plant on earth: a floating, rootless plant the size of a pin's head. Yet it has been used as a vegetable by Burmese, Laotians, and the people of northern Thailand for many generations. The species also occurs in India. The plant's Thai name *khai-nam* means "eggs of the water" and refers to its oval shape. It is a nutritious food: Analysis has shown it to be (dry-weight basis) 20 percent protein, 44 percent carbohydrate, and 5 percent fat. Regarded as a "poor people's" food, khai-nam is a potentially significant source of nourishment that has not been widely recognized as such or exploited outside of Thailand.

Villagers in northern Thailand cultivate *Wolffia arrhiza* in open rain-fed ponds. The prolific plants are harvested every 3–4 days during which time the few unharvested plants multiply into a thick, yellowish-green mass of plants at the water's surface. (In the laboratory *Wolffia arrhiza* has been found to double its numbers in 4 days or less.) Longer intervals between harvests yield a brown, dead plant that is unattractive and less valuable.

The weekly yield of fresh, marketable plants (averaging 4 percent dry matter) averages 0.68 kg per m^2 per week. In the climatic conditions of Chiengmai in northern Thailand, khai-nam remains in its edible vegetative form between November and July and its inedible form between August and October. The calculated annual yield is 265 tons per ha fresh weight, or 10.5 tons per ha dry weight, which means that *Wolffia arrhiza* produces more dry matter than conventional vegetable crops grown in Thailand.*

Animal Feed

Duckweeds are relished as food by herbivorous fish, ducks, geese, swans, and other wild fowl, and–as noted already–by cattle and pigs. Recent results of feeding duckweed to poultry, though still preliminary, look promising. Research aimed at harnessing duckweeds as agricultural crops is in its infancy, but experiments are being conducted at Louisiana State University with species of *Spirodela* grown on lagoons used to dispose of wastes from swine and dairy cattle. These nutrient-rich wastewaters yield plants with exceptional protein content: 37–45 percent (cf: alfalfa, 17 percent; soybeans, 37 percent; and cottonseed meal, 41 percent).

*Information on *Wolffia arrhiza* supplied by M. G. McGarry. (See Research Contacts.)

Typical analytical figures follow:

Constituent	Percentage (dry weight)
Nitrogen	6–7 percent
Phosphorus	1.4–3 percent
Potassium	1.5–3 percent
Calcium	1 percent
Ash	8–14 percent
Fiber	7–10 percent
Fat	4–6 percent
Metabolizable energy	1958 calories/kg

The high nitrogen value (6–7 percent) rivals that of inorganic fertilizers, which are normally only 8 percent nitrogen, and makes spirodela attractive as a fertilizer. But the low ash and fiber contents and the high protein seems to make it an ideal candidate for animal feed. Recently in fertilized outdoor ponds in Louisiana, *Spirodela oligorhiza* and *Spirodela polyrhiza* have doubled their biomass every 3 days, producing the equivalent of about 500 kg of dry matter per hectare per day during the growing season (9 months). If this were harvested each day, crude protein produced annually by 1 ha of duckweed would equal that now obtained from about 60 ha of soybean.*

The few analyses that have been made show that duckweed is richer than alfalfa in lysine and arginine (two amino acids important in animal feeds) but slightly poorer in methionine.

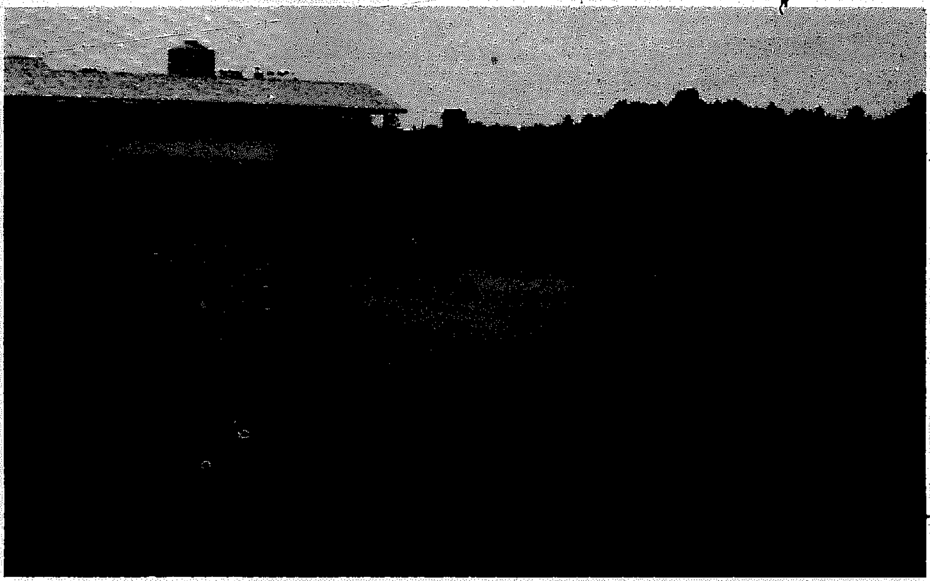
Wastewater Treatment

Species of *Wolffia*, *Lemna*, and *Spirodela* show promise for use in recovering nutrients from wastewater. It is thought that they absorb nutrients through both the root and lower surface of the frond. An exponential growth rate enables a colony of duckweeds to absorb considerable quantities.

During the growing season in the southern United States, doubling times for *Spirodela oligorhiza* range from 3 to 7 days. Calculations based on doubling time of 7 days (i.e., 7 days to double in biomass) show that *Spirodela oligorhiza* growing on a 1-ha lagoon will remove the nitrogen, phosphorus, and potassium of 207 dairy cows occupying a milking parlor 4 hours per day and fed standard U.S. rations.

Doubling times of 5 days have been recorded for species of *Lemna* grown on a wastewater lagoon in subtropical Louisiana. Monthly yields have ranged from 1.7 to 6.7 tons per ha (dry weight) depending on the nutrient

*Information on *Spirodela* grown on farm-waste lagoons supplied by D. D. Culley. (See Research Contacts.)



At a dairy near Baton Rouge, Louisiana, wastes from a milking shed are washed into a neighboring lagoon planted with duckweed (*Spirodela* spp.). The plants can aid in purifying such lagooned wastewaters by absorbing large quantities of nutrients. In experiments at Louisiana State University duckweeds are being mixed into poultry, swine, and cattle rations to test their suitability as feed ingredients. (D. D. Culley)

availability. Crude protein content approached 40 percent on a dry-weight basis.

In truly tropical climates it is likely that doubling times of 3 days can be achieved. (In laboratories doubling times as low as 16 hours have been recorded.) Under such conditions a small farm pond, easily harvested by hand, could provide much forage for domestic animals.

Floating, without any attachment to the soil, duckweeds are easy to harvest by skimming the surface with a rake or net. (In Louisiana experimental ponds are now being built in which the water level can be raised to float the duckweeds off the surface and into perforated troughs that drain away the water; the animals will then eat the fresh weeds right out of the trough.)

Limitations

Floating on the water surface, colonies of duckweed are easily broken up by wind and waves. On waterways more than 0.5 ha in area much of the weed can pile uselessly on the banks if wind protection is not provided (see figure p. 119). As with the waste-treatment lagoons growing other aquatic plants

(Chapter 13), lagoons with duckweed provide a breeding place for mosquitoes. Generally, however, a full cover of duckweed suppresses mosquito breeding, and harvesting should be done so that large areas of shallow, open water do not remain for more than a few days.

Year-round duckweed-growing is limited to tropical regions. In cooler areas plants grow vigorously only during warmer months.

Like other aquatic plants, duckweeds contain much moisture (90–95 percent), and handling and transporting them in large quantities is difficult and expensive. Sun-drying is practical in areas where humidity and rainfall are low; mechanical dewatering has not been attempted systematically.

Some samples of *Lemna* contain large amounts of oxalic acid; this may prove to be a widespread occurrence, thereby limiting the use of *Lemna* spp. in some animal feeds.

Sexual reproduction is rare in duckweeds; almost all reproduction is vegetative. On a waterway all samples of a duckweed are usually descended from the same original frond and have the same genetic makeup (i.e., they are clones). While their ability to grow fast, absorb nutrients, and withstand adverse environments is identical, it may differ greatly from clones of the same plant that are growing in other areas. Thus, results in one region may not be replicable in another unless the same clone is used.

Research Needs

Small size makes duckweeds easy to culture and a favorite organism for biological study. Although hundreds of scientific articles are available in the literature, these deal almost exclusively with the detailed biology of a mere handful of common species. Lesser known duckweeds occur in many developing countries, and good research opportunities exist for testing indigenous species for growth rate, chemical content, nutritive value, ability to clean up wastewaters, and palatability to domestic animals, waterfowl, and fish.

Despite the biological literature, virtually nothing is known of the use of duckweeds as food, feed, fertilizer, or in wastewater treatment. In addition, techniques for planting, maintaining, harvesting, and handling duckweeds have not been perfected. There remains much room for ingenuity and methodical research.

A potentially important aspect of duckweed growth in wastewater has been recently uncovered at Michigan State University. It has been found that the duckweeds *Lemna minor* and *Lemna trisulca* concentrate boron at least 10 times more than other aquatic weeds growing with them in a pond. Since boron is essential for some crops (though toxic to others) the unusual capacity of the duckweeds for scavenging boron might be useful.

This ability to concentrate metals may be an important avenue for duckweed research with commercial potential. Samples of *Lemna minor* harvested from the American River in California have been found to have absorbed aluminum from the water to such an extent that 1 kg of the duckweed contained as much aluminum as 660,000 liters of the water in which it was growing. (Furthermore, manganese was concentrated 461,000-fold, iron 307,000-fold, titanium 102,000-fold, copper 79,000-fold, and cobalt 26,000-fold).*

In order to realize the duckweeds' potential as beneficial crops, strains will have to be selected for rapid growth, for quality as end-product (e.g., animal feed), and for other qualities. The plants must also be made to flower and set seed in order to obtain the necessary genetic variability. Methods have been developed for only one species,† and wider success poses a considerable challenge to plant and agricultural scientists.

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Appendix B Biographical Sketches of Committee Members

LARRY O. BAGNALL is an associate professor of agricultural engineering at the University of Florida, Gainesville. He received a B.S. in agricultural engineering from Washington State University in 1957 and a Ph.D. from Cornell University in 1967. He has been a member of NAS panels that participated in workshops on aquatic weed problems in Guyana, the Sudan, and Egypt. Also he has built presses for dewatering aquatic weeds in Guyana and Bangladesh. His research area is forage harvesting and processing, with specialization in aquatic plants.

WILLIAM M. BAILEY, JR., is the Special Projects Coordinator and Supervisor of Fish Hatcheries for the Arkansas State Game and Fish Commission. He received a B.S. in biology from Arkansas State University in 1967 and did graduate work at the same University and at Mississippi State University. He is certified as a fisheries scientist by the American Fisheries Society. He joined the staff of the Game and Fish Commission in 1969. Since 1971 he has been in charge of Arkansas' White Amur (grass carp) Program. He has experimented extensively with artificial reproduction techniques for grass carp and conducted field studies on the use of carp in lakes for weed control. In 1972 he won the Rochester Prize for Scientific Information for his paper entitled "Arkansas' Evaluation of the Desirability of Introducing the White Amur for Control of Aquatic Weeds." He has written several publications on grass carp and related topics. In 1976 he introduced grass carp to Egypt and advised the Sudanese government on their grass carp program.

HOWARD W. CAMPBELL is a research zoologist in the U.S. Fish and Wildlife Service. As Chief of the Gainesville, Florida, field station of the National Fish and Wildlife Laboratory, he has responsibility for directing the Fish and Wildlife Service's sirenian (manatee and dugong) research program, and for supervising a wide range of endangered species and environmental programs in the southeastern United States. He received his B.A. in zoology from the University of Florida, and his M.A. and Ph.D. in ecology from the University of California at Los Angeles. He has served on the faculty of the University of Florida, as a private ecological consultant, and as a staff biologist for the Office of Endangered Species and International Activities in Washington, D.C. He holds positions on the conservation committees of several professional societies and the Interim Steering Committee of the International Centre for Research on Manatees.

DUDLEY D. CULLEY, JR., is Associate Professor of Fisheries in the School of Forestry and Wildlife Management at Louisiana State University. He received a B.S. in 1959 from Millsaps College; M.Ed. in 1961 from the University of Mississippi; M.S. in 1963 and Ph.D. in 1968 in zoology from Mississippi State University. He is an expert in water pollution biology, aquatic ecology, and amphibian biology. Current research interests include the recycling of animal wastes into animal feeds and energy and the use of aquatic plants in waste treatment. He is currently serving as an advisor to the Institute of Environmental Studies and the Office of Water Resources Research Institute at Louisiana State University, and is a special advisor on the Louisiana Attorney General's Scientific Advisory Committee. Teaching duties at the university have included water pollution biology, ichthyology, and ecology of aquatic plants.

THOMAS deS. FURMAN is a professor of civil engineering and professor of environmental engineering sciences in the College of Engineering of the University of Florida, Gainesville. He received a B.S. in Civil Engineering from The Citadel in 1936 and an M.S.E. in Sanitary Engineering from the University of Florida in 1950. He is a registered professional engineer in South Carolina and Florida and is a diplomate of the American Academy of Environmental Engineers. He has served as a design consultant to numerous engineering firms and is currently a Director of Water and Air Research, Inc., in Gainesville, Florida. His expertise lies in the area of water and wastewater collection, treatment, and disposal, with special emphasis on the problems of small communities.

JOHN F. GERBER is the Director of the Center for Environmental Programs and Natural Resources in the Institute of Food and Agricultural Science at the University of Florida, Gainesville. He taught for ten years in the Department of Fruit Crops before being named Assistant Dean for Research at the same institution. He received a B.S. in 1956, an M.S. in 1957, and a Ph.D. in soils in 1960 from the University of Missouri. He is a specialist in agriculturally related environmental problems (including aquatic weeds) with interests in meteorology, climatology, and horticulture, fields in which he has published extensively.

CLARENCE G. GOLUEKE is a Research Biologist III at the Sanitary Engineering Research Laboratory and lecturer in the Division of Sanitary Engineering at the University of California, Berkeley. He received an A.B. in zoology from St. Louis University in 1939, a M.A. in plant ecology from the University of Illinois (Urbana) in 1941, and a Ph.D. in mycology from the University of California (Berkeley) in 1953. He is a specialist in biological waste treatment and on the technological aspects of agricultural and municipal solid wastes management. He serves as a consultant to the U.S. Environmental Protection Agency on solid waste management, and is on the editorial board of three technical journals.

JAMES F. HENTGES, JR., is a professor of animal science in the College of Agriculture and ruminant animal nutritionist in the agricultural experiment station of the Institute of Food and Agricultural Sciences, University of Florida, Gainesville. He received a B.S. in animal science at Oklahoma State University in 1948 and a Ph.D. in biochemistry–animal science at the University of Wisconsin in 1952. Currently, he supervises beef cattle and water buffalo research at three research farms in Florida and teaches undergraduate, graduate, and continuing education courses. He was a member of the NAS panel that, in 1973, participated in a workshop on aquatic weed management and utilization in Guyana. In 1975 he was chairman of the NAS panel that participated in workshops on aquatic weed problems in the Sudan and in Egypt. His expertise lies in the fields of ruminant animal nutrition, physiology, and enterprise management.

RICHARD G. KOEGEL is an assistant professor of mechanical and agricultural engineering at the University of Wisconsin, Madison. He received a B.S. in mechanical engineering and agriculture at the University of Wisconsin in 1956, an M.S. in irrigation and drainage engineering from Utah State University in 1962, and a Ph.D. in agricultural engineering from the University of Wisconsin in 1971. He has worked in agricultural engineering in South Vietnam and the Niger Republic as well as in the United States. At present he is part of a multidisciplinary team conducting a project on harvesting aquatic weeds and converting them into soil conditioners, conversion into protein concentrates for food, and fermentation to methane.

CLARENCE D. McNABB is a professor of limnology in the Department of Fisheries and Wildlife at Michigan State University, East Lansing, Michigan. He received an A.B. from Loras College in 1951, and an M.S. and a Ph.D. in botany from the University of Wisconsin, the latter in 1960. A portion of his research is concerned with the role of aquatic plants in lakes that daily renovate up to 2 million gallons of wastewater from the Michigan State University campus. He has studied aquatic weeds and their utilization in North America, in New Zealand, at the Max Planck Institute in West Germany, and in South America. He has served as a consultant to government agencies and industrial corporations in the United States.

JULIA F. MORTON is a research associate professor of biology and Director of the Morton Collectanea, University of Miami, which is a research and information center devoted to economic botany. She received her Ph.D. from Florida State University in May 1973 and was elected a Fellow of the Linnean Society of London in November 1974. She is a member of the Council for Agricultural Science and Technology, the Society for Economic Botany, the Florida State Horticultural Society, and the American Society of Pharmacognosy. She is the author of 60 papers and 6 books on botanical and horticultural subjects and a contributor to others. She has conducted extensive field studies for the National Institutes of Health and the Department of Defense; has served as horticultural development consultant in tropical America; and, since 1954, has been consultant for the Poison Control Centers of Florida.

B. DAVID PERKINS is a research entomologist with the Agricultural Research Service, U.S. Department of Agriculture, Fort Lauderdale, Florida. He received a B.A. from the University of Richmond in 1958, an M.S. from Virginia Polytechnic Institute in 1961, and a Ph.D. from the University of Hawaii in 1966. He is a specialist in biological control of weeds, particularly aquatic weeds. He has conducted biological weed control research in Europe (1965–1967), in Argentina (1967–1971), and in Florida (1972–present) and is currently a member of the USDA Southern Region Advisory Group on Biological Control of Insects and Weeds. He has served on NAS panels that participated in workshops on aquatic weeds in the Sudan and Egypt, and he is involved in a continuing project with the Sudanese-German Water Hyacinth Control Project in the Sudan.

HUGH POPENOE is a professor of soils, agronomy, botany, and geography; Director of the Center for Tropical Agriculture and International Programs (Agriculture) at the University of Florida, Gainesville; and the Director of the State University System of the Florida Sea Grant Program. He received his B.S. from the University of California at Davis in irrigation and Ph.D. in soil science from the University of Florida. He is a specialist in tropical land use and ecology and has served on numerous committees to various government agencies and private institutions, including the American Society of Agronomy, Gulf Universities Research Consortium, Latin American Scholarship Program of American Universities, Foreign Area Fellowship Program, National Association of State Universities and Land-Grant Colleges, Council of Sea Grant Directors, Sea Grant Association, and the National Academy of Sciences.

ERNEST ROSS is a professor of animal science at the University of Hawaii, Honolulu. He received a B.S. in poultry science from the University of Arizona in 1946, and an M.S. in 1951 and a Ph.D. in 1955 in poultry nutrition from the Ohio State University. Although the major thrust of his research is concerned with the nutritional value of tropical feedstuffs, he has varied interests. These include the nutrition of prawns, sea turtles, and geese. He has pioneered the deliberate use of geese to control aquatic weeds.

DAVID L. SUTTON is an associate professor of agronomy at the USDA Agricultural Research Center at the University of Florida, Fort Lauderdale. He received a B.S. from Berea College in 1963, and an M.S. in 1965 and a Ph.D. in 1968 from Virginia Polytechnic Institute and State University, Blacksburg. He is a specialist in biological and chemical control of aquatic weeds, and has written numerous articles. He is Editor of the *Journal of Aquatic Plant Management* and serves on the editorial board of *Aquatic Botany*.

BILLY C. WOLVERTON is a senior scientist with NASA's National Space Technology Laboratories at Bay St. Louis, Mississippi. He received a B.S. in chemistry from Mississippi College in 1960, with three years of graduate studies in biochemistry and microbiology at the University of Mississippi and one year of graduate work in marine biology at the University of West Florida. He was a research chemist with the Department of Defense from

1963 to 1971 and has extensive experience in environmental effects from hazardous and toxic substances. He has conducted extensive research in the utilization of vascular aquatic plants for removing pollution from waterways and for producing energy, food, and fertilizer.

RICHARD R. YEO is a research botanist for the Agricultural Research Service of the U.S. Department of Agriculture and is located in the Botany Department of the University of California at Davis, California. He received his B.S. in 1950 and M.S. in 1952 in wildlife management and botany, respectively, at Michigan State University. He obtained his Ph.D. at the University of Minnesota in 1960, majoring in agronomy–soils. He has been with USDA since 1957 and is an expert on managing undesirable aquatic vegetation using biological, chemical, and mechanical techniques. He has been a member of NAS workshop panels on aquatic weed problems in Guyana, the Sudan, and Egypt, and he has been involved in introducing new aquatic weed controls to Africa.

NOEL D. VIETMEYER, staff officer for this study, is a Professional Associate of the National Academy of Sciences. A New Zealander with a Ph.D. in organic chemistry from the University of California, Berkeley, he now works on innovations in science that are important for developing countries. He has studied the dewatering and utilization of aquatic weeds since 1967 and has been staff officer for workshops on aquatic weed problems in Guyana and in the Sudan, as well as for a workshop in Guyana on the use of manatees for aquatic weed control.

Resumen en Español

Introducción

La amenaza que representan las hierbas acuáticas está llegando a proporciones alarmantes en muchas partes del mundo. El agua es un recurso importante, y las hierbas acuáticas tienen en él un efecto adverso, bloqueando los canales y las bombas en los proyectos de irrigación; interfiriendo la producción de energía hidroeléctrica; desperdiciando el agua en la evapo-transpiración; obstaculizando el tráfico de botes; aumentando las enfermedades propagadas por el agua; interfiriendo la pesca y los cultivos de peces; y obstruyendo los ríos y canales de modo que su drenaje se hace imposible y resultan inundaciones.

Este es un problema generalizado, pero reviste características particularmente severas en los países tropicales en los que el agua más cálida y el número creciente de represas y de proyectos de irrigación fomentan el crecimiento de plantas acuáticas. El problema se agrava más todavía con el creciente enriquecimiento del agua causado por las fugas de fertilizantes y nutrientes vegetales procedentes de desperdicios humanos y agrícolas. En la India, grandes proyectos de irrigación han sido inutilizados por las plantas que obstruyen los canales, disminuyendo el flujo del agua hasta en cuatro quintos de su caudal. Los granjeros de las tierras bajas húmedas de Bangladesh tienen que enfrentarse cada año al desastre producido por grandes masas de jacinto acuático, que pesan hasta 150 toneladas por acre, que se ciernen sobre sus plantíos de arroz, impulsadas por las inundaciones. Cuando las aguas finalmente se retiran, las hierbas quedan sobre el arroz que está germinando, sofocándolo. Los ingenieros del Canal de Panamá han estimado que sería imposible pasar por el Canal en el término de tres años si no tomaran de modo continuo las medidas de control de malezas.

A medida que las hierbas acuáticas se multiplican, dispersan las babosas que causan la esquistosomiasis, una enfermedad insidiosa y debilitante que prevalece en muchos países en vías de desarrollo. Estas babosas viven sobre las raíces colgantes de la hierbas y son transportadas por éstas impulsadas por el viento y las corrientes. Además, las plantas acuáticas favorecen la diseminación de la malaria, de la encefalitis y de otras enfermedades causadas por los mosquitos, puesto que los charcos pequeños y protegidos, perfectos para la reproducción de los mosquitos, se forman entre las plantas flotantes.

Sin embargo, en cierto sentido, las hierbas acuáticas constituyen un cultivo gratuito de un gran valor potencial; un cultivo altamente productivo que no necesita mano de obra, fertilizantes, siembra o cosecha. Las plantas acuáticas tienen potencial para su explotación como alimento para los animales, como alimento para la gente, como aditivos para el suelo, para producción de combustible y para el tratamiento de aguas de deshecho.

En la medida que las serias implicaciones de orden negativo de la presencia de las hierbas acuáticas son más ampliamente reconocidas, científicos, ingenieros y administradores gubernamentales están comenzando a tomar acción al respecto. Desafortunadamente no existe ninguna manera sencilla de reducir las infestaciones. Los herbicidas que matan las hierbas acuáticas y los medios mecánicos son casi los únicos métodos utilizados en los países en vías de desarrollo. Ambos medios son costosos y muchos países en vías de desarrollo deben gastar sus divisas escasas para importarlos. Inclusive, cuando los importan, a menudo es imposible utilizar, los métodos químicos y mecánicos debido a las dificultades de mantenimiento y de acceso a las regionas lejanas o pantanosas. Además los productos químicos pueden tener un efecto adverso en el medio ambiente, y las grandes cantidades de desperdicios orgánicos en descomposición que producen pueden interferir la reproducción de la fauna acuática.

Este informe estudia una alternativa: la utilización de las hierbas acuáticas para su conversión en alimento, fertilizantes, papel y fibras, y energía. A continuación se presenta un resumen de los principales puntos discutidos.

La Carpa

Un pez de rápido desarrollo que se alimenta de las plantas, la carpa prefiere las hierbas sumergidas suculentas (las que son difíciles de controlar usando técnicas convencionales) convirtiéndolas en carne altamente cotizada. Aunque la carpa es originaria de los ríos de aguas heladas de Siberia Rusa y China, medra en las aguas tibias del trópico y puede llegar a pesar 40 kgs. Su reproducción natural es limitada fuera de habitat nativo, pero se le puede reproducir artificialmente. (Capítulo 1)

Otros Peces Herbívoros

Hay poco conocimiento sobre los hábitos de alimentación de muchos peces de las regiones tropicales. Una investigación de amplio alcance sobre las especies herbívoras podría localizar aquéllas que son de importancia para el control de hierbas acuáticas. Entre las especies citadas que ameritan ser estudiadas y probadas están las especies *Tilapia*, el "dólar de plata" de América del Sur y la carpa plateada. (Capítulo 2)

Manatíes (Vacas Marinas)

Estos mamíferos del trópico, casi extintos, son excepcionalmente eficientes en la eliminación de las hierbas de los canales. Comen diariamente muchos kilogramos de hierba y pueden consumir muchas especies diferentes. Hasta que se pueda desarrollar su crianza y reproducción en cautividad, sólo podrán ser útiles en sus países de origen en América Latina y Africa Occidental, y entonces únicamente si se les protege y conserva adecuadamente. (Capítulo 3)

Langostinos

Entre los organismos comestibles menos explotados, estos parientes cercanos de la langosta son altamente cotizados como plato de gastrónomo. En el Estado de Louisiana, los langostinos son reproducidos en gran escala en los plantíos de arroz donde se alimentan de las hierbas acuáticas, de los rastrojos restantes después de la cosecha del arroz, y de pequeños organismos acuáticos. (Capítulo 4)

Patos, Gansos y Cisnes

Si se les maneja cuidadosamente, estos herbívoros comunes pueden eliminar notablemente las hierbas acuáticas. Al hacerlo, proveen carne y huevos. Constituyen un potencial prometedor en especial para el uso de pequeños granjeros en países en vías de desarrollo. (Cápitulo 5)

Otros Herbívoros

Muchos animales viven de las plantas, pero nunca se ha llevado a cabo un estudio sistemático sobre los animales herbívoros apacentados productivamente con hierbas acuáticas. Entre los animales que merecen ser estudiados están las capibaras, las nutrias, los burros, cerdos y corderos. La investigación efectuada sugiere que, si se le maneja cuidadosamente, el búfalo acuático puede alimentarse con plantes acuáticas, como el jacinto acuático. (Capítulo 6)

Cosecha

Los campos cenagosos infestados generalmente de hierbas acuáticas son muy difíciles de cosechar, sin embargo, se han desarrollado algunos medios ingeniosos para hacerlo. Algunos de ellos se ilustran. (Capítulo 7)

Dehumidificación

El alto contenido de humedad es la única diferencia de mayor importancia entre la vegetación acuática y la terrestre. De ordinario las hierbas acuáticas contienen solamente del 5 al 15% de sólidos. Para transportarlas o usarlas para alimento animal o para otros propósitos, debe eliminarse previamente gran contenido de humedad. Los métodos que actualmente están en desarrollo son la eliminación del agua por medios mecánicos o mediante el secado al sol. (Capítulo 8)

Aditivos del Suelo

Los fertilizantes están críticamente en escasez en muchos países en vías de desarrollo. Muchas hierbas acuáticas tienen cantidades apreciables de nitrógeno, fósforo, potasio y otros ingredientes de los fertilizantes. Además, las hierbas acuáticas utilizadas como fertilizante pueden emplearse para mejorar la textura del suelo, lo que es de vital importancia en suelos arenosos, de laterita o altamente arcillosos–los que están ampliamente distribuidos en los países en vías de desarrollo. (Capítulo 9)

Alimentos Procesados para Animales

Las hierbas acuáticas frescas tienen usualmente demasiada humedad para utilizarlas eficientemente como forraje. Más aún, muchas no son apetitosas para las principales razas de ganado vacuno y para los carneros. Extrayendo parte del aguy y y ensilando los residuos constituye una técnica prometedora para su uso en los países en vías de desarrollo. El jacinto acuático ensilado y otras hierbas acuáticas han sido aceptadas aún por ganado habituado a dietas de calidad. (Capítulo 10)

Pulpa, Papel y Fibras

En Rumania, se produce pulpa y papel en gran escala extraídos de las hierbas acuáticas fibrosas, de tipo como carrizos; en otras zonas del mundo, se utilizan las hierbas acuáticas para empajar, para muebles, esteras tejidas, cestas, etc. El papiro, del que se originó el primer material parecido al papel para escribir, y el junco están sin que se les conceda importancia pero son recursos prometedores. (Capítulo 11)

Energía

En un proyecto en Mississippi la Administración Nacional de la Aeronáutica y del Espacio (NASA, el programa espacial de los E.U.A.) está fermentando el jacinto acuático para producir metano. Este proyecto experimental ofrece un método mediante el cual las hierbas acuáticas pudiesen convertirse en combustible. (Capítulo 12)

Tratamiénto de Aguas de Desperdicio

Los compuestos de nitrógeno y fósforo son agentes contaminantes comunes de las aguas: al mismo tiempo son los principales ingredientes de los fertilizantes. Algunas hierbas acuáticas pueden extraer estos materiales del agua e incorporarlos en su propia estructura. Los investigadores en un buen número de laboratorios han encontrado recientemente que estas plantas pueden usarse para el tratamiento de las aguas de desperdicio de modo que los nutrientes disueltos en ellas pueden recobrarse para su reciclaje. Actualmente se están realizando experimentos para purificar las aguas cloacales municipales, las aguas de desperdicio industriales y de granjas de crianza de cerdos y lecherías, reproduciendo en ellas plantas acuáticas. (Capítulo 13)

Plantas Acuáticas para Alimento, Usos Misceláneos

Solamente una planta acuática es utilizada ampliamente como cultivo con propósitos alimenticios—el arroz. El castaño acuático chino, el berro y otras especies menos conocidas aparentan ser dignas de aumentar su explotación. (Capítulo 14)

Resumé en Français

Introducción

La menace que représente la flore aquatique prend des proportions alarmantes dans de nombreuses régions du monde. L'eau étant une ressource vitale, les plantes aquatiques ont sur elle une incidence particulièrement fâcheuse : elles bloquent les installations de pompage et les canaux d'irrigation, elles gênent la production de houille blanche, elles contribuent à l'évaporation par la transpiration, elles entravent la navigation sur les cours d'eau, accroissent les risques de transmission de maladies dont l'eau est le vecteur, elles contrecarrent la pêche et la pisciculture et, obstruant les rivières et canaux, elles s'opposent à l'écoulement des eaux et sont la cause d'innondations.

Se posant à l'échelle mondiale, ce problème est particulièrement aigu dans les pays tropicaux où la tiédeur de l'eau, l'aménagement croissant des rivières et une irrigation accrue encouragent la prolifération des plantes aquatiques. Il est encore aggravé par un enrichissement incessant des eaux naturelles grâce aux apports d'engrais dus au ruissellement et de matières nutritives provenant des activités humaines et agricoles. Aux Indes, d'importants réseaux d'irrigation ont été rendus inutilisables par la croissance des plantes aquatiques qui, en bloquant les canaux, ont réduit des quatre cinquièmes l'apport d'eau. Les exploitants de subsistance des terres basses du Bangladesh sont tous les ans au bord du désastre quand des amas flottants de jacinthes d'eau, pouvant peser jusqu'à 300 tonnes à l'hectare, sont apportés dans leurs rizières par les eaux en crue. Les plantes, laissées sur place par la décrue, étouffent le riz en train de germer. Des ingénieurs ont estimé que le canal de Panama ne serait plus navigable au bout de trois ans sans une lutte permanente contre l'envahissement des herbes aquatiques.

Des gastéropodes aquatiques vecteurs de la schistosomiase, cette maladie insidieuse et débilitante qui sévit dans de nombreux pays en développement, élisent domicile sur les racines flottantes des plantes aquatiques qui, voguant au gré des vents et des flots en étendent l'aire de dispersion à mesure qu'elles se multiplient. En outre, par les petites mares abritées qu'elles forment entre elles, lieu d'élection pour la reproduction des moustiques qui en sont les vecteurs, elles encouragent la transmission de maladies comme le paludisme et l'encéphalite.

Et pourtant, il faut reconnaître que la flore aquatique constitue une culture gratuite d'une grande valeur potentielle : elle ne demande ni labours ni engrais ni semences ni culture. Elle offre de grandes possibilités en matière de fourrage, d'alimentation humaine, d'amélioration des sols, de production de combustible et de traitement des eaux résiduaires.

A mesure que l'on reconnaît les aspects négatifs graves de la présence d'herbes aquatiques, les scientifiques, les ingénieurs et les responsables gouvernementaux commencent à prendre les mesures correctives qui s'imposent. Malheureusement, la lutte contre cette prolifération n'est pas simple. Les herbicides et les moyens mécaniques sont pratiquement les seuls procédés en usage dans les pays développés. Ils sont onéreux, et les pays en développement doivent consacrer à leur importation leurs maigres ressources en devises. Même dans ce cas, les procédés chimiques et mécaniques sont souvent inutilisables en raison de la difficulté d'entretien et de l'inaccessibilité de certaines régions ou des zones marécageuses. En outre, les produits chimiques peuvent avoir une incidence fâcheuse sur l'environnement et les grands volumes de substances organiques en décomposition qui en sont le résultant peuvent entraver la pisciculture.

Le présent rapport étudie une solution éventuelle : la transformation des plantes aquatiques en aliments, en engrais, en papier et fibres et, enfin, en énergie. Les principaux points suivants y sont examinés :

La Carpe Herbivore

Poisson à croissance rapide qui se nourrit de plantes, la carpe herbivore préfère les herbes charnues immergées, contre lesquelles il est difficile de lutter par les moyens classiques, les transformant en une chair particulièrement appréciée. Bien qu'elle soit originaire des eaux froides de la Sibérie et de la Chine, elle s'accommode des eaux tièdes des tropiques et certains individus peuvent atteindre jusqu'à quarante kilos. Comme elle se reproduit mal hors de son milieu natif, il faut recourir à l'insémination artificielle (chapitre 1).

Autres Poissons Herbivores

On connaît mal les habitudes alimentaires d'un grand nombre de poissons tropicaux. Une large campagne de recherche sur les espèces herbivores pourrait permettre de découvrir celles qui présenteraient un intérêt indéniable pour la lutte contre la flore aquatique. On cite parmi les espèces qui méritent un effort de recherche et d'expérimentation les *Tilapias*, le "dollar d'argent" d'Amérique du Sud et la carpe argentée (chapitre 2).

Lamantins

Ces mammifères tropicaux herbivores en voie d'extinction ont la capacité exceptionnelle de débarrasser les voies d'eau de leurs herbes aquatiques. La consommation journalière de ces animaux se traduit par dizaines de kilos et, en outre, ils s'attaquent à plusieurs espèces. Tant qu'il ne sera pas possible d'assurer leur reproduction et leur élevage, ils n'auront d'utilité que dans leur habitat naturel : les pays d'Amérique du Sud, d'Amérique centrale et d'Afrique si, toutefois, des mesures spéciales sont appliquées en vue de la protection et de la conservation de l'espèce (chapitre 3).

Ecrevisses

Parmi la faune commestible la moins exploitée des eaux douces il faut compter ce crustacé, proche parent du homard, et que les amateurs payent un bon prix sur les marchés. Dans l'Etat de Louisiane les écrevisses font l'objet d'une culture à grande échelle dans les rizières où elles se nourrissent de chaume de riz, de plantes et de petits organismes aquatiques (chapitre 4).

Canards, Oies et Cygnes

En s'y prenant de la bonne façon, ces oiseaux herbivores pourraient être d'un grand secours pour la lutte contre les herbes aquatiques. Ils fournissent également une bonne chair et des oeufs. Ces volatiles sont particulièrement prometteurs pour les petits exploitants des pays en développement (chapitre 5).

Autres Animaux Herbivores

Il existe de nombreux animaux qui se nourrissent de plantes mais aucune étude systématique n'a encore été faite pour savoir si la flore aquatique pourrait leur servir de fourrage vert. Parmi ceux qui méritent d'être étudiés on compte notamment un rongeur amphibie d'Amérique du Sud, le capybara (Hydrochoerus capybara), une loutre, la nutria, ainsi que des singes, des porcs et des moutons. Des travaux de recherche récents laissent à penser que le buffle d'eau pourrait, dans de bonnes conditions, se nourrir de plantes aquatiques, la jacinthe d'eau en particulier (chapitre 6).

Récolte

La récolte est extrêmement difficile dans les zones marécageuses généralement envahies de plantes aquatiques. Toutefois, pour la faciliter, on a mis au point des dispositifs ingénieux dont quelques-uns sont illustrés (chapitre 7).

Déshydratation

La seule différence importante entre les végétaux terrestres et aquatiques est la forte teneur en eau de ces derniers. Il ne contiennent en effet que 5 à 15 pour cent de matière solide. Il convient donc de les déshydrater pour en permettre le transport ou l'emploi comme fourrage. Des procédés de dessication utilisant l'énergie mécanique ou solaire sont actuellement en cours d'étude (chapitre 8).

Adjuvants des Sols

Dans de nombreux pays en développement les engrais font sévèrement défaut. Beaucoup de plantes aquatiques contiennent en quantité appréciable de l'azote, du phosphore, du potassium et d'autres substances fertilisantes. Au surplus, et ceci est extrêmement important, on peut les employer à l'amendement des sols sableux, latéritiques et fortement argileux qui se retrouvent partout dans les pays en voie de développement (chapitre 9).

Fourrage Traité pour Animaux

A l'état frais les plantes aquatiques ont en général une trop forte teneur en eau pour fournir un bon fourrage. Au surplus, les principales races de bovins et d'ovins se refusent à consommer la majorité d'entre elles. Leur déshydratation partielle et leur ensilage pourait produire des résultats avantageux dans les pays en développement. C'est ainsi que la jacinthe d'eau et d'autres végétaux aquatiques sont devenus grâce à ces méthodes, fort appréciés du bétail habitué à des rations de qualité (chapitre 10).

Pulpe, Papier et Fibres

En Roumanie, on produit de la pulpe et du papier à partir de plantes aquatiques fibreuses ressemblant à des roseaux. Dans d'autres pays on se sert de ces végétaux comme chaume pour les toits, pour faire des meubles, de la sparterie, de la vannerie, etc. Le papyrus, l'ancêtre du papier, et la canne de jonc (typha) quoique encore négligés représentent une ressource intéressante (chapitre 11).

Energie

La NASA, dans un de ses laboratoires de l'Etat de Mississippi, étudie la possibilité de tirer du méthane de la jacinthe d'eau par fermentation. Le projet n'en est encore qu'au stade expérimental mais il offre une méthode permettant la conversion de certains végétaux aquatiques en un combustible précieux (chapitre 12).

Traitement des Eaux Usées

Les composés azotés et phosphorés sont les pollutants les plus courants des cours d'eau. Ce sont également les composants principaux des engrais. Certaines plantes aquatiques ont la faculté d'extraire ces substances de l'eau et de les assimiler. Un grand nombre de chercheurs ont récemment découvert que ces végétaux pouvaient être utilisés dans le traitement des eaux résiduaires, les nutriments en solution étant ainsi récupérés en réemploi. Des essais sont actuellement en cours sur la purification des eaux usées d'origine urbaine, industrielle ou agricole, particulièrement les porcheries et les laiteries, en y faisant pousser des plantes aquatiques (chapitre 13).

Flore Aquatique dans l'Alimentation, Usages Divers

Une seule plante herbacée aquatique, le riz, est largement utilisée comme culture vivrière. Une châtaigne d'eau (Eleocharis tuberosa), le cresson et d'autres espèces moins connues semblent mériter une exploitation plus poussée (chapitre 14).

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