National Science Research Council of Guyana

and

National Academy of Science, U.S.A.

WORKSHOP ON

AQUATIC WEED MANAGEMENT AND UTILISATION

"Some Prospects for Aquatic Weed Management in Guyana"

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NATIONAL SCIENCE RESEARCH COUNCIL
OF GUYANA

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'Some Prospects for Aquatic Weed Management in Guyana"

GEORGETOWN, GUYANA, MARCH 15 — 17 1973

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INTRODUCTION

A three-day workshop on the Management and Utilisation of Aquatic Plants was held in Georgetown, March 15 - 17, 1973,to formulate recommendations addressed to one of Guyana's critical problems – the weeds that infest the nation's waterways.

Jointly sponsored by the National Science Research Council of Guyana (NSRC) and the National Academy of Sciences of the United States (NAS), the workshop was charged to develop recommendations for implementation by local authorities to:

1. deal with the aquatic weed problem, particularly by utilising the vegetation as a resource for products, such as animal feeds and soil additives, needed by Guyana;
2. develop outlines of integrated systems of aquatic weed management in Guyana using biological, physical, and chemical methods.

An excellent keynote address, which officially opened the deliberations of the workshop, was given by the Prime Minister of Guyana, Mr. L.F.S. Burnham, O.E., S.C. He stated that his main interest in the workshop was in the uses to which aquatic plants could be put in Guyana. Noting that the workshop was being sponsored jointly by the National Science Research Council of Guyana and the National Academy of Sciences of the United States, the Prime Minister said that this was the type of collaboration his government welcomed at all times for it presented an unselfish sharing of knowledge for the improvement of mankind.

A number of distinguished observers attended the opening of the workshop including Mrs. Burnham, the wife of the Prime Minister; the Deputy Prime Minister and Minister of National Development and Agriculture, Dr. Ptolemy A. Reid; the Ambassador of the United States, Mr. Spencer M. King; the Director of the United States Agency for International Development Mission, Mr. Robert C. Hamer; the British High Commissioner, Mr. W.S. Bates; and the Ambassador of Brazil, Brig. - General Jose da Cunha Garcia.

At the conclusion of the workshop, practical demonstrations were held at the Bel Air Dairies on the outskirts of Georgetown. Demonstrations of methods for harvesting water plants included the use of plastic shoes that permit one to walk on water. Also, a press designed by Dr. Larry Bagnall, one of the NAS panelists, was used to remove moisture from water hyacinth, the first step in producing animal feeds and soil additives. Subsequently, the press cake was fed to cows, and also made into hay.

The demonstrations were attended by the Prime Minister and his family, Dr. Reid, Mr. King, Mr. Hamer, a representative from the World Bank, and numerous Guyanese engineers and agriculturalists.

Arrangements were made for the U.S. panelists to visit a sugar estate, the Botanic Gardens to observe manatees, an agricultural research station, and a dairy farm. In addition, the Bookers Company arranged for flights in a small plane to give the panelists an overview of the waterway systems and aquatic weed problems in the East Demerara area.

This report is published with the expectation that the observations, findings, and recommendations will be of value to a wide audience in Guyana, and to planners, agriculturalists, and others in developing countries worldwide who are faced with aquatic weed problems.

This is the first cooperative NSRC-NAS activity. In 1972 Dr. Reid indicated to USAID his interest, and that of the Government, in applying the latest scientific and technical knowledge to convert to useful products the large amount of vegetation clogging Guyana's waterways. The NSRC of Guyana

and USAID in turn requested NAS support to review the current knowledge of processing aquatic vegetation and to recommend programmes suitable for Guyana.

Support for the organisation and facilities of the workshop was provided by the NSRC. Participation of the Academy panel members and staff support was made possible through assistance from the Office of Science and Technology, Technical Assistance Bureau, AID, Washington. The generous support from these organisations is greatly appreciated.

Recognition and thanks are due to the many individuals who contributed long hours and dedicated efforts to make the workshop a success. Credit must go to the members of the NSRC organising committee, especially Dr. & Mrs. Irvine and the staff of the National Academy of Sciences who helped with the coordination of the workshop, and to the workshop participants whose deliberations were the essence of the meeting.*

Assistance in preparing the final report was given by members of both panels and by the rapporteurs of the working groups. Final preparation of the report was the responsibility of the NSRC.

* Mr. Hamer and Mr. Bowen of USAID provided valuable assistance with the arrangements for the US panelists.

CHAPTER 1
PRINCIPLES AND RECOMMENDATIONS

Principles

There are three approaches to the control of aquatic weeds: via methods that use herbicides; via biological methods that use living organisms to attack the weeds or manipulate the natural environment to harm them; and via physical methods that shred the weeds or remove them from the waterways by harvesting.

The panel considers that no single method will prove a panacea; the most lasting aquatic weed management and the most beneficial to Guyana as a whole will be a blend of the different methods in which the benefits of each are maximised and their limitations minimised. For example, harvesting weeds may be satisfactory in accessible waterways when one species of plant predominates, but in less accessible waters, or in those with mixed stands, it may be best to use biological agents or herbicides. In other cases existing stands may be too dense and woody for a biological agent to be very effective. The best approach may then be to attack the stand with herbicides, or to harvest and use a biological agent only as a follow-up to keep down the palatable regrowth. In general, all methods of aquatic plant control complement each other and should not be considered competitors.

When appropriately controlled, aquatic plants can play a vital constructive role in the aquatic environment by

- Producing oxygen
- Serving as food, nest-building material, and sites for egg attachment for aquatic insects and fish
- Protecting small organisms from predation
- Converting silt and dissolved nutrients in the waterway to potentially useable organic matter
- Serving as food for birds, fish and land animals
- Anchoring soil in place

The benefits are proportional to plant density but only to a certain limit; when the plants form very dense or extensive stands the detrimental aspects outweigh the benefits and the plants become an economic burden. (See Chapter 2).

Aquatic weed management should be aimed to maximise and to capitalise on the benefits the plants bring to the country. Thus, waterway clearing should be conducted in an amount appropriate to fishing, public health, navigation, drainage needs, and to the use of the plants as a vegetation resource and water purification tool. These often do not call for eradication.* To plan for aquatic plant management of this kind a scientific team with biologists and specialists in ecology, agronomy, horticulture, engineering, animal nutrition, soil science, economics, and systems management may be needed.

Before choosing any weed control method for use in the field, the first step should be to consider methods that might decrease the source of the weeds – prevention is much better than cure,

* Few weed control methods can destroy the roots, tubers, and rhizomes of submersed and emergent weeds because they are buried in the mud. Such rooted structures can be reached only by a few animals that dig them out (e.g. water-fowl), and by complex machinery that blasts away the mud with water jets. Therefore, eradication of submersed and emergent weeds is close to impossible today.

Consideration should always be given to any change in weed species that might occur after clearing a waterway. In the United States, for example, areas completely cleared of water hyacinth have been invaded and occupied by underwater weeds which have proved more difficult and expensive to control. Thus, eradication can sometimes be undesirable.

A consideration in choosing any method is that small plant fragments can float away and colonise new sites. This is a consideration with all three methods, as well as in the case where the weeds are left uncontrolled.

Examples of such methods are: strict control of the movement of aquatic weeds to ensure that weed-free waters are not infected (weeds are often distributed as fragments caught on boat hulls, as packing for produce and tropical fish, and as ornamental plants for fishponds); and quarantining or banning the import of foreign aquatic plant species (a favourite of tropical fish fanciers).

This report emphasises rearing wild or domesticated animals which feed on aquatic vegetation, because agricultural or living patterns that encourage Guyanese people to raise these may also benefit aquatic weed control programmes and provide income, food, and improved nutrition at the same time. The approaches recommended may not prove practical or advantageous elsewhere in the world.

Recommendation 1. Continuing Committee on Aquatic Weed Management

The control of aquatic weeds falls under the interests and responsibilities of the Ministry of National Development and Agriculture, the Department of Drainage and Irrigation, the Water Conservancy Board, the Department of Fisheries, city and town Councils, the Water Authority, and the sugar estates.

The National Science Research Council should create a continuing committee on aquatic weed management for Guyana with membership from all organisations that have authority over, or are interested in, the country's waterways.

The National Science Research Council can provide a common meeting ground for the scientists from such organisations so that successes and failures with aquatic weed control measures can be compared, and the communications opened up by the workshop continued.

Recommendation 2. Action to Restrict the Introduction of Foreign Aquatic Weeds and the Spread of Weeds Already Present

The best way to deal with a difficult pest is to keep it out. Guyana is fortunate not to have some aquatic weeds that cause major economic problems elsewhere in the world. Guyana should institute extreme measures to protect against the introduction of these and any other aquatic vegetation that could worsen the existing problem.

It is essential that responsible officials and students be made aware of the appearance of plants that have to be guarded against. Illustrated posters and instructional literature will be needed. Customs officers should include in their responsibilities a careful look-out for aquatic plants.

This education needs to be reinforced by appropriate legislation to make it difficult to import such plants.

The Botanical Gardens should also be included in the ban on exhibiting or holding imported aquatic plant species that could become pests. It is unwise to import such plants even for scientific study, but if it is necessary the studies should be conducted under conditions of strict quarantine.

Some foreign and potential problem-causing aquatic weeds alien to Guyana are:

Ceratophyllum demersum
Cyperus papyrus and other **Cyperus** species
Egeria densa
Elodea canadensis
Hydrilla verticillata
Lagarosiphon major
Myriophyllum spicatum
Najas species
Scirpus cubensis and other **Scirpus** species
Trapa natans
Typha species
Vossia species.

Not only is it important to restrict importation of new aquatic plants but great care must be taken to prevent the spread of aquatic weeds to parts of the country now free of them. Aquatic weed problems appear to be restricted to the coastal belt at present. Yet the interior's waterways are vulnerable, and with increasing use of them for agriculture, domestic use, and hydro-electricity, now is the time to institute preventative measures that will minimise the threat of their becoming infected with aquatic weeds not already present.

Recommendation 3. Utilisation of Processed and Unprocessed Aquatic Weeds

A. **Designate an engineer** to be responsible for a project on "Harvesting and using the Bagnall Press for processing aquatic plants." This project will also require a full-time crew to harvest, chop, press, and transport water hyacinth press residue.

Comparative data on the harvesting and processing of all the major aquatic plants in Guyana should be obtained.

The performance (water removal, production rate, and power requirement) of the press and related

equipment should be evaluated under a variety of conditions, modifications made, and operating procedures optimised. Support equipment and improved or larger presses may be designed, built and tested, as experience dictates.

B. **Designate an animal nutritionist** to be responsible for a project entitled "Utilisation of aquatic plants in livestock diets". Assigned to the project would be the engineer described above who would provide aquatic plant press residue for studies.

This project should include making silage. For this, pilot silos will be required. These can be 55-gallon drums fitted with a small drainpipe to remove seepage.

The pilot silos might be filled with water hyacinth as follows:

- Silo No. 1 - chopped plants only
- Silo No. 2 - chopped and pressed plants
- Silo No. 3 - chopped and pressed plants with 10% molasses*
- Silo No. 4 - chopped and pressed plants with 10% molasses and 25% wheat middlings
- Silo No. 5 - chopped and pressed plants with 10% molasses and 12.5% wheat middlings, and 12.5% rice bran
- Silo No. 6 - chopped and pressed plants with 10% molasses, 12.5% wheat middlings, and 12.5% peanut hulls
- Additional Silos - Above treatments with a preservation such as formic, acetic, or propionic acid.

Chemical analyses should be made on fresh and ensiled materials to determine the following:

Dry matter	Crude protein
Organic matter	Silage acidity

After 60 days, each treatment should be offered to groups of 5 ruminating cattle and/or 5 mature sheep in standardised acceptability tests.

The most economical and most palatable silage produced in the pilot silos should be produced in larger silos and fed to a larger number of animals as a full-scale field trial and demonstration. This might best be done in a silo located on the bank of a convenient waterway.

* These materials are added as percentage of the dry matter in the press residue.

Aquatic weed other than water hyacinth should be tested in the pilot silos, using the most successful ensiling process.

C. **Designate a soil scientist** to be responsible for a project entitled – "Utilisation of harvested aquatic plants for soil improvement".

This project should seek to evaluate potting materials made from water hyacinth (fresh whole plants, and residue from the Bagnall Press) in combination with materials such as tree bark, wood shavings, rice hulls, poultry house litter, peat, sand, clay, and sugar mill residues.

Concurrently, a study should be initiated to measure the effect of adding the combinations to various vegetable gardens with soil types representative of those found throughout the country.

Recommendation 4. Trials with Herbivorous Fish

Certain species of herbivorous fish, selected for the large quantities of vegetation they consume, have been studied as controls for excessive growths of aquatic weeds. **White Amur, Tilapia,** and **South American Silver-dollar Fish** are receiving the greatest attention currently.

It is recommended that 1,000 young white amur (**Ctenopharyngodon idella**) and 1,000 young Tilapia (**zillii**) be brought to the Guyana Fish Hatchery for research studies (under strict quarantine) to determine their ability to survive and control aquatic vegetation, and their potential to become marketable, edible fish in Guyana.

Both these fish ingest stems and foliage with little or no waste. Both could exploit Guyana's crops of aquatic weeds to produce highly prized, nutritious meat that could contribute to the Guyanese diet. They might eventually prove a commercially valuable resource.

Local fisheries scientists should determine the potential of the fish to survive, grow, and control weeds in different types of waterways.

To conduct this research six ponds where good-quality water can be supplied and replenished during the course of the studies would be adequate. Two holding ponds should be approximately 0.5 acre and 2.5 to 3.1 feet deep. The remaining four ponds would be for experimentation and should each be approximately 0.25 acre and 2.5 to 3 feet deep. The facility should be surrounded by a chain-linked security fence, topped with barbed wire, to maintain a quarantine until such time that the fish are proven acceptable for use in Guyana.

Experiments should include:

- testing the palatability of different kinds of troublesome aquatic plants found in Guyana;
- testing the size of the fish necessary to withstand predation by the native fish;
- improving the ability of the fish to survive in Guyana waters, such as in the waterway systems of the sugar estates, in flood-fallowed fields, in rice paddies, canals, and reservoirs For these studies the acidity, oxygen content, and general water chemistry should be taken into account.

A previous introduction of the white amur into Guyana was unsuccessful. They were eaten by native predaceous fish shortly after thay had been released. To overcome this problem should be a major thrust of the proposed research.

The threat of white amur infesting Guyanese waters is slight; to spawn, it requires highly specialised waterway conditions that occur in Siberia, its native home, and it is unlikely that spawning will occur in Guyana. The fish can, however, be spawned artificially under hatchery conditions so that, should it prove useful, a supply of fish can be maintained.

Tilapia aureae and **T. mossambica** are now being studied at the Guyana Fish Hatchery, but **T. zillii** is more aggressive and may have a better chance of surviving predation.

Some important candidates for weed control may be found among Guyana's native fish. These have the advantage that they have learned to survive in the presence of local predators and a study of them is recommended. For example, the locally termed "Paku" eats weed voraciously, and it is reported that aquarium-fish collectors in Guyana are able to collect them readily. Care must be taken, however, for young pakus can be confused with young piranhas. In canals and empoundments paku will not have their normal spawning conditions of fast running, highly aerated water. Spawning may have to be done in a hatchery.

Recommendation 5. Manatees

It was demonstrated in the Georgetown area a decade ago that manatees can keep select waterways free of most types of Guyana's aquatic weeds. This concept may be much more relevant and acceptable today, and it is recommended that trials to use manatees for practical weed control in carefully selected canals, lakes, and permanent reservoirs be instituted.

These trials would serve to re-awaken local interest in this concept which is virtually unique in Guyana. Today's concern over pesticides, and the worldwide search for alternatives, may very well provide the impetus that will project the use of manatees into a routine and ongoing role in the arsenal of aquatic weed controls in Guyana.

The Cozier and Prashad Nagar canals were recommended to the panel as being particularly suited for a practical test of the value of manatees as weed control agents in Guyana today. Both of these are overflow canals used as safety valves for their respective conservancies during time of flood. Keeping them clear of weeds, silt, and blockage is critically important, and at present they are cleared of weeds by hand.

Poaching will be a constant concern wherever manatees are used, and though the general populace in the region surrounding the two canals is reported to be likely to act responsibly in this matter, it may take a radio or poster campaign to educate the people to the value of the manatees' weed-clearing efforts.

Both Cozier and Prashad Nagar canals are patrolled by rangers who could be put in charge of the manatees' interests. The project will, however, require part-time support from a biologist.

The attention of the relevant authorities is drawn to the necessity for improved enforcement of the manatee protection laws already on the statute books in Guyana.

An International Manatee Research Centre. The long-term practical use of manatees for weed control in waterways in general is contingent upon accumulating knowledge of manatee nutrition, procreativity, and pathology, leading to the development of proper husbandry procedures.

Almost nothing is known about the breeding habits and reproduction of the manatee. The gestation period, age at sexual maturity, length of the reproductive cycle, frequency of reproduction, and life expectancy are all matters of judicious speculation. Manatees have never bred in captivity, and it will be necessary to carry out a complete physiological and reproductive study of the animal in order that its breeding can be fully understood.

Research is urgently needed to stimulate reproduction and to speed it up, so that what presently is a slow reproductive process can be made more regular, and to produce more calves. Perhaps superovulation, artificial insemination, or

hormonal stimulation can be effected.

If satisfactory reproduction and husbandry can be achieved by this research it could bring benefits to tropical countries worldwide. These include: Sudan, Zaire, Uganda, Nigeria, Pakistan, Bangladesh, Thailand, Indonesia, Philippines, New Guinea, United States (Hawaii and Florida). Earlier work in Guyana stimulated correspondence from 43 countries where manatees could be of value.

Guyana is the most logical place in the world to conduct this research. Both the Caribbean manatee (**Trichechus manatus**) and the Amazonian manatee (**T. inunguis**) are native to Guyana; the former to the coastal region, and the latter in the south. Guyanese scientists have had more experience with manatees than any others (their records on the animals go back to at least 1878). Probably more is known in Guyana about their handling than anywhere else in the world; individuals experienced with their capture are available; and the Drainage and Irrigation Department have a truck specially fitted to move manatees.

Temperatures in Guyana are ideal, year round, for manatee research, and although it would be done in artificial conditions manatees could also be studied in their native habitats close by.

Also, Guyana has the land and possibly some existing canals that could be the basis for a manatee research centre.

To outline the best course of action to begin a manatee biology research programme in Guyana, an international steering group should be established. Through this the best directions to be taken will be identified, but tentative suggestions to aid readers to visualise some approaches are made below:

The research should put primary emphasis on manatee reproductive physiology, pathology, and husbandry. All species should be considered because the Amazonian and African (**Trichechus senegalensis**, Link, 1795) ones are smaller and may be more easily handled than the Caribbean species, they may reproduce more readily, they may have a more useful growing cycle, and they may control weeds more efficiently. Although what is known of the Caribbean species is little, the other two are completely unstudied.

Numbers of animals suitable for study might be in the order of 40 Caribbean, 4 pairs of Amazonian, and 2 pairs of African manatees. It is considered by local scientists that this number of the first two could be obtained easily in Guyana, but obtaining the African manatees may be difficult.

The Centre should be organised to promote the interlocking and exchange of ideas and results between complementary disciplines. Local veterinary scientists should play a major role in the Centre's research, but specific competence in mammalian reproductive physiology is needed, and valuable experience may be gained from scientists who have worked on elephants, porpoises, whales, etc. Some of the goals should be:

- to compare the African, Caribbean, and Amazonian species;
- to understand the reproduction cycle and reproductive physiology;
- to induce and stimulate breeding;
- to learn the manatee's dietary requirements and to develop dietary supplements, weaning foods, and a manatee milk substitute;
- to develop a breeding herd.

All of these goals will require long-term research.

The physical structures for the Centre might include a canal system covering several acres of land. The canals should be able to be fed separately and might be some 15 feet across, 8 feet deep. To avoid having to transport weeds in, the canals should be extensive enough (or have shallow embayments) to produce a good supply of weeds.

The site could be in one of the conservancies, or adjacent to a sugar estate or distributary. It should have access to a veterinary laboratory, and for this and for general ease of access should probably be in the East Demerara area.

Recommendation 6. Biological Controls

Three short-growing species of spikerushes (**Eleocharis coloradoensis, E.acicularis** and **E.parvula**) have been found to compete successfully with rooted submersed aquatic weeds.* The plants grow so close together that they look like underwater lawns. They "crowd" out and displace neighbouring aquatic weeds and also prevent the weeds re-entering an area where the "lawn" has been established. Although one of the requirements for successful establishment of the spikerushes is adequate light penetration and most of Guyana's waters are turbid, it is likely that some Guyanese waters are clear enough for them to flourish.

* Some tall-growing species of **Eleocharis** exist in Guyana and are locally known as "water" or "alligator" grass.

It is recommended that propagules* of the three species of spikerushes be brought into Guyana, and a study made of their potential to displace harmful weeds. The investigations should be conducted under quarantine conditions.

None of the species has proved to be a pest in California where all three are native. They are found in canals leading to rice fields, but have not become weeds in the fields, but this possibility should be explored.

Water Fowl. Husbandry of domestic water fowl could become important in Guyana as a self-supporting adjunct to conventional aquatic weed management. Operated as family businesses by farmers and estate workers (or their families), the birds could improve nutrition, health, and bring income to the operators.

Water-fowl can remove vegetation from waterways. They are especially effective in small ponds for the control of duckweed. Geese have been reported to control aquatic grasses with considerable success in Hawaii,** and it is well known that many birds eat the succulent young shoots of other free-floating and submersed plants. Birds can also retard plant reproduction – the fruits and seeds of wide-spread emergent and submersed plants provide the most important food of many types of water-fowl (e.g. coots, ducks, geese, grebes, and swans) and are also commonly eaten by marsh birds, shore birds, and game birds. Meat and eggs from these birds provide some of the best eating known.

Domesticated water fowl including white Chinese geese, Muscovy ducks, etc. are potentially useful to Guyana. Though they will have little impact on the overall weed problem their production as a cottage industry should be encouraged. The birds must be domestic varieties and must be kept out of the rice fields.

Insects. The possibility that most insects, currently under investigation elsewhere in the world, could be utilised as controls for aquatic weeds in Guyana is remote. However, the "water hyacinth weevil", Neochetina eichhorniae, which is currently a leading insect candidate for the biological control of water hyacinth, is found in the interior of Guyana. If detailed surveys confirm that this weevil is absent from the coastal region of Guyana, as is now thought, their importation from the Rupununi (Moreru Lake) region and/or Argentina, where another useful species N.bruchi also occurs, is likely to provide a certain amount of water hyacinth control. A project to make a survey of the distribution of N.eichhorniae in Guyana might be appropriate as university student research. Similarly an inventory of the insects attacking other aquatic weeds would permit more definite recommendations to be made.

Recommendation 7. Chemical Control

Control of aquatic weeds using herbicides has proved effective on sugar estates in Guyana.

The problem with herbicides is made more difficult in Guyana by water turbidity, for some of the safest herbicides are deactivated on contact with silt. Pentachlorophenol was previously used extensively. However, it killed fish and tainted the water, and its use is now being reduced. Triazines are currently used, and apparently they control weeds adequately and without harming fish. Although considerable research has been conducted on triazine herbicide residues, the safety in potable and irrigation waters in Guyana needs to be determined more precisely.

Herbicides are a suitable answer, but the workshop panel notes that the use of herbicides should not be a long-term policy, and that if adequate alternatives can be found they should be encouraged.

Invert emulsions might make herbicides more effective in the rainy season when aqueous sprays wash off. The mayonnaise-like texture makes the herbicide adhere to the foliage better.

A proposal was made that Guyana should set up a pesticide committee or authority to monitor pesticide levels in water which is used for domestic purposes.

Recommendation 8. Aquatic Weeds and Hydroelectricity Development

Although all electric power in Guyana is now produced in thermal power stations, many potentially valuable hydroelectric sites exist in the interior and schemes to utilise them are under consideration. The rivers are similar to those of Surinam and much can be learned from the hydroelectric scheme at Brokopondo in Surinam.. As with most tropical man-made lakes, the still water behind the newly formed Brokopondo dam encouraged "explosion" of

* Available from Dr. Richard R. Yeo, Dept. of Botany, University of California, USA.

** E. Ross, "Biological Control of Pond Weeds with White Chinese Geese", Hawaii Farm Science, Vol. 20; No. 2, p. 11, 1971.

aquatic plants which were previously innocuous. In 1964 it was reported that about 12 square miles of Brokopondo Reservoir was infested with water hyacinth.*

Mats of plants add to the cost of operating dams; they clog intake machinery and must be constantly removed. Aquatic plant infestation is also costly in hydroelectric facilities specifically, because power production depends on the head of water in the reservoir, and the plants reduce this because they occupy a portion of the dammed area and because they evaporate water at a rate several times that from a free water surface.

* E.C.S. Little, "The Invasion of Man-made Lakes by Plants" in "Man-made Lakes", R.H. Lowe-McConnel, Ed; Academic Press, London, 1966, p.75.

In light of the probable development of costly weed infestations, hydroelectric schemes in Guyana should prepare preventative measures that will avoid the reservoirs' becoming infested with aquatic weeds.

Preventative measures might include: removing trees in areas where they might later interfere with aquatic weed harvesting; planning harvesting and utilisation programmes in conjunction with reservoir planning; treating patches of weeds with herbicides while they are still manageable before the reservoir fills; stocking the rising waters with herbivorous fish, manatees, etc.; preparing to obtain a supply of any insect or pathogen that might be needed to keep the plant growth manageable; maintaining a stockpile of herbicides and equipment to eradicate outbreaks should they occur. These measures may not be cheap and they should be taken into account when the cost of dam construction is calculated.

CHAPTER 2
BACKGROUND

The name "Guyana" originates from an Amerindian word which means "water" or "a watery country" Guyana is a part of the Amazon-Orinoco watershed and it is broken up by many waterways. Eight rivers drain the land and flow into the sea along a coast length of only 120 miles.

Communication with the interior is chiefly by river. There are only 374 miles of trunk roads in Guyana; a density of one mile of road to 222 square miles of country, one of the lowest in the world. One reason for this is the ease of access by water to remote areas.

Guyana has three distinct geographical areas – the Coastal Region, the Sand and Clay Belt, and the Mountain Region. The Coastal Region is about 270 miles in length and varies in width from 10 to 40 miles. Ninety percent of the population lives here though it comprises only 4 per cent of the country.

Drainage is towards the Atlantic in the north and northeast but overall it is poor; the average gradient of the main rivers is only one foot per mile. Even in the mountains and savannahs there are extensive swamps, and flooding is prevalent. Stream flow varies widely with the seasons: June and July begin the peak "flood" months, March and April being the months of least flow.

Drainage and irrigation systems grew haphazardly throughout the 18th and 19th centuries. Now the coastland is ribboned by agricultural blocks, each with its own drainage and irrigation canal system. Most of the area is below sea level, and is protected to its north from the Atlantic Ocean by a system of dykes and sea defences, and, in the higher land to the south, by earthworks enclosing "conservancies" which are large shallow catchment areas. These provide irrigation water, and when full comprise some 400 square miles of water surface. Gravity drainage is possible only at low tides, and this is supplemented by pumps that push the unwanted water, including used irrigation water, over the sea walls.

The drainage and irrigation system of Guyana's coastal plain is extensive and costly – so costly as to make small-scale operations not worth the effort in some areas. Many areas have had to be abandoned, and new areas have proven expensive to open due to the poor drainage of the plain. All new settlement projects require extensive drainage control before they are suitable for agricultural use. The largest single item in development budgets since 1958 has been "drainage and irrigation". The land is drained and irrigated mainly to plant rice.

Sugar estates in Guyana have two extensive and separate canal systems – the low-level "sidelines" with their field drains which are for drainage, and the high-level "middle-walks" and "cross-canals" that are used for transport and irrigation. It has been estimated that for each square mile of cultivated cane there are 16 miles of high-level canals, 4 to 5 miles of low-level canals, and 45 miles of small field drains. In both high and low-level canals the control of aquatic weeds has always been a recurrent and difficult problem.

AQUATIC WEEDS FOUND IN GUYANA*

Aquatic weeds are classified as floating, submersed, emergent or algae. The major aquatic weed species in Guyana are listed below:

Floating	Local Name
Eichhornia crassipes	Water hyacinth
Pistia stratiotes	Water lettuce
Neptunia plena	Sour bush
Salvinia sp.	Alligator eye
Azolla sp.	Water velvet

* This section is based largely on Bates (1954)

Paspalum repens	Shrimp grass
Submersed	
Cabomba aquatica	Shrimp "moss"
Utricularia intermedia	Lead "moss"
Elodea sp.	Chinese "moss"
Emergent	
Nymphaea sp.	various lilies
Nelumbo sp.	"Lotus" lily
Marsilea quadrifolia	Pepperwort
Montrichardia sp.	Moka-moka
Caladium sp.	Wild eddo

Floating Types. Floating weeds are often found in "middlewalk" and "cross" canals where the flow is not great. They tend to accumulate, and are frequently so dense as to block the passage of small boats and cane punts. Water hyacinth (**Eichhornia crassipes**), water lettuce (**Pistia stratiotes**), and Shrimp grass (**Paspalum repens**) cause particular problems.

In the wider navigation canals, floating weeds are moved by wind and water currents, and though they do not interfere with the flow of water they present a constant threat to the movement of small boats.

Water lettuce is very abundant in navigation canals.

Water hyacinth is the most renowned aquatic weed and causes severe economic devastation throughout the tropical and sub-tropical world. Although native to South America it has been carried by well-meaning individuals, enraptured by its pretty flowers, to all the continents. Originally described from Brazil in 1823, it has an extensive range from Brazil to Venezuela, and is particularly abundant in the Pernambuco region, the Amazon basin, and the lower Orinoco. It may also be native to parts of Central America and the larger Caribbean islands where it extends, although some of its stations in this area might be due to early introduction. In Guyana **E.crassipes** is accompanied by **E.azurea**, and some minor species of **Eichhornia**. It is very remarkable that whilst the other members of the genus, and also the exclusively African **E.diversifolia**, have all apparently remained within the limits of their native range, **E.crassipes** has spread far and wide during the past 80 years.

Water hyacinth reproduces principally by vegetative means, daughter plants (offsets) are produced by stolons which grow laterally below the water surface from the central rhizome, the interconnected plants forming enormous mats of vegetation.

One of the reasons for water hyacinth's success is its rapid rate of offset production which furnishes it with a very efficient means of reproduction. These offsets are buoyant, and their sail-like leaves allow them to float rapidly from place to place; floating mats, solitary drifting plants, and fragments are all too readily distributed by water currents, strong winds, and passing boats. When a plant or suitable fragment arrives at a new habitat, it can establish a new population by its own offset production. Thus, the weed spreads very quickly.

In habitats where the water is shallow, exposed, and at a high enough temperature for germination (and where the soil is suitable), propagation by seeds may contribute to the spread of water hyacinth, and can be a potent source of reinfestation of cleared areas. The seeds remain viable during dry periods.

Salvinia auriculata, first described as from "Guiana", has spread over a wide area in Central and South America, from Cuba to Argentina. A sterile hybrid of it is now in Southern Africa, in Zaire, Cameroon, and Southeast Asia. It first "exploded" and became a serious problem in Ceylon in the early 1950's. By 1956 Salvinia had covered an estimated 22,000 acres of rice fields and 2,000 acres of waterways (Williams, 1956). Later it threatened Lake Kariba; in 1962 it covered 1,000 sq.km. or 386 sq. miles, about 21% of the lake's surface (Nitchell, 1969).

Also deserving special mention are members of the duckweed family **Lemnaceae L.** A single frond may be the size of a pinhead, and there are no stems or true leaves. Members of this family propagate vegetatively by producing new individuals at the edge of the frond. They can cover the surface of an entire pond in a few weeks. Duckweeds are a nusiance in rice fields, and cause trouble in irrigation systems by entering siphon tubes and pumps and by collecting on trashracks.

Paspalum repens, shrimp grass, forms dense floating clumps, particularly in the Berbice area.

Neptunia plena sometimes forms large inter-twined growths, with individual stems often attaining a length of 8 feet. It is a leguminous plant that is "sensitive" to being touched. Other Neptunia species are found throughout the tropics, and cause problems in rice cultivation and irrigation schemes in West Africa, Madagascar, the Sudan, Ceylon and India, Malaysia, and the Philippines (Sculthorpe, 1967).

Submersed Weeds. An important problem of shallow water (less than 5 feet deep) in Guyana is the growth of underwater weeds (locally called 'water mosses'). Submersed weeds are particularly difficult to control with herbicides, because the waterway

dilutes the herbicide and because the fish are also exposed to the chemicals. They are also difficult to harvest.

Notable submersed weeds in Guyana are **Cabomba aquatica** ("Shrimp moss"), **Utricularia intermedia** (Bladderwort or "Lead moss"), and **Elodea sp.** (Waterweed or "Chinese moss"). These three species constitute the major weed problem of canals. Cabomba comprises over 80% of all the "mosses" in Guyana. Its growth is so rapid that it often eliminates all other competing weeds.

Submersed weeds are particularly abundant in waters which drain from highly acidic peat soils (locally termed pegasse).

Emergent Weeds. These are rooted plants which extend above the water surface. In Guyana they are of the sedge or lily type. Plants of this kind often grow outwards from canal banks or shoreline and overgrow the water.

Emergent weeds in Guyana include:

1. small white, pink, and blue water lilies **(Nymphaea sp.)**
2. the large lotus lily **(Nelumbo sp.)**
3. the giant Amazonian water lily **(Victoria regia)**
4. the Pepperwort, **Marsilea quadrifolia**, is quite common, particularly in cross canals, where there is little movement of water.

The sedges, which are represented by several species of **Cyperus** and **Eleocharis** (often called "water" or "alligator" grass), and the locally named "jussea grass", **Fimbristylis miliacea**, are not generally troublesome weeds, except along the margins of newly dug canals in pegasse areas. In abandoned canals the large Moka-Moka (**Montrichardia arborescens**) and Wild Eddoe (**Caladium sp.**) are usually abundant, and are often found in poorly drained cane fields. The Wild Starch (**Canna sp.**) is often found along canal banks, and recently this species has become common in mechanically prepared fields.

Other plants that grow in Guyana but which are minor contributors to aquatic weed problems are species of:

Typha (cattail)
Myriophyllum (water milfoil)
Potamogeton (pond weed)
Vallisineria
Ceratophyllum
Ruppia
Sagittaria e.g. **Sagittaria guyanensis H.B.K.**
Luziola
Mimosa
Hymenachne
Ipomoea (morning glory)
Panicum
Leersia
Alternanthera

Algae. Algae, e.g. **Chara** and **Nitella sp.** are found in canals in Guyana but, generally, are troublesome only in small areas and are of little economic importance.

AQUATIC WEEDS AND NAVIGATION

Aquatic weeds have curtailed river transportation by blocking waterways in some areas, not only in Guyana but on the Nile, the Congo, in Florida, and elsewhere. Commercial ships have been delayed or stopped in each case. In addition, costly damage to boats has occurred; propeller shafts, cooling systems, and rudders are jammed by the plants. Drifting mats of water hyacinth have piled up against bridge pilings to such heights that their weight skewed the entire structure from its base (Coleman, 1957). Logs and snags concealed by the vegetation create a hazard to navigation.

In Guyana's rivers the main problem is grass islands – mainly **Paspalum repens, Hymenachne amplexicaulis** and **Leersia sp.** No chemical control is carried out except in the Georgetown area. In 1972 grass islands completely blocked the Canje Creek.

In the larger canals (an estimated 3,500 miles) floating masses of water hyacinth, water lettuce, and **Paspalum sp.** seriously impede water transport.

AQUATIC WEEDS AND DRAINAGE

Aquatic weeds are a menace to water systems. Dense colonies of them may occupy up to 10% of the total volume of a waterway. Using water-soluble dyes, it has been determined in Guyana that heavy infestations of "mosses" reduce the flow of water in small canals by as much as 75%, reducing the system to uselessness. Weeds also increase evaporation and seepage losses, cause damage to canal walls, and clog grates, siphons, valves, and sprinkler heads (Bates, 1954).

In the low-level drainage canal system (some 500 miles) the major problem weeds are **Cabomba** and **Utricularia** species. **Cabomba** is wide-spread in all middle-walks and sidelines, although its presence is often not noticed because of surface weeds and water turbidity.

Reduced flow deposits sediment and lessens channel capacity by raising the bottom of the waterway, and this is worsened by accumulations of decaying debris

that fall from aquatic plants during growth. This debris alone may raise the canal bottom by more than 30 centimeters per year. Newly deposited silt and decaying vegetable matter encourages establishment of rooted aquatic plants. All of these reduce drainage and increase chances of flooding.

In Malaya (Coleman, 1957), where rivers ceased functioning as flood channels when they became clogged with water hyacinth, the flood waters swept over farm land. During heavy rainfall the low-lying coastal areas of Guyana face danger of flooding too. Flood waters accumulate in the highlands, and if their free passage through the coastal drainage canals and pumps is slowed, flooding can result.

AQUATIC WEEDS AND AGRICULTURE

Aquatic weed problems in irrigation channels cannot be separated from those just described, for in Guyana drainage and irrigation are linked. In providing irrigation water for crops in Guyana one must also drain the land and dispose of the water when it has served its purpose. Dense aquatic weed growth affects these operations, and unimpeded flow of water is essential to avoid flooding.

Irrigation water is supplied, mainly by gravity, from the conservancies. Aquatic weeds in the conservancies, as well as in farm ponds and shallow areas of lakes, reduce their utility for water storage, irrigation, and fish production. Not only do plants occupy space that could be filled with water, but the loss of water by transpiration through floating or emergent aquatic weeds is often greater than three times the loss from a free water surface. Indeed Sculthorpe (1967) postulates that transpiration from the leaves of water lettuce could be six times greater, and the loss through water hyacinth was reported by Das (1969) as 7.8 times that from open water.

Sugar and rice are Guyana's major crops, and in cultivating both a unique technique of "flood-fallow" is practised. Fallow land is left flooded for six months and more to improve soil tilth and fertility and to leach away salts accumulated during irrigation. The acreage under flood-fallow at any one time varies between eight to twelve thousand acres. No attempt is made to control weeds in flood-fallowed fields. During this period growth of aquatic weeds may become dense, and this magnifies the aquatic weed threat to neighbouring waters. Aquatic weed residues are left in the fields after the flooding and, though they interfere with planting the next crop, they do act as a green mulch.

Infestations of aquatic weeds are serious problems during the initial growth period of rice seedlings, and in Guyana, as elsewhere in tropical lands, rice paddies have been lost to cultivation by invasion of aquatic weeds. Rice, an aquatic plant itself, is also attacked by pathogens living on nearby stands of aquatic weed; the weeds maintain a reservoir of such pathogens.

Aquatic weeds in the sugar estate irrigation canals also interfere with movement of the punts used to carry cut cane from field to mill, and one of the preparations for cane harvest is to clear aquatic weeds from the middlewalks.

AQUATIC WEEDS AND FISHERIES

Some inland water areas of Guyana produce good catches of fish and estimates of the country's fish potential are impressive. Inland fishing could produce four to five million pounds of fish annually. The government hopes to develop fishing as a means of reducing the country's dependence on fish-food imports. It is hoped to develop the fish industry through improvement of facilities and by encouraging "fish farming" as a commercial land-use practice. A governmental project has already devoted 57 acres of ponds to a feasibility study of fish culture.

Aquatic plants provide a direct or indirect source of food for fish. The plants increase the populations of algae, bacteria, and other micro-organisms which provide food for the larger invertebrates which, in turn, provide food for fish. Also stands of submersed plants provide natural spawning media for egg-scattering and nesting fishes, and subsequently afford the protection, shade, and food needed by the fry.

Fishing is often good around patches of lily pads, over deeply submerged plants, and on the edges of beds of submersed weeds which rise near the surface. Rural fishermen in Southeast Asia, Bangladesh, and India have learned to encourage this by erecting circles of bamboo stakes into which they deliberately plant water hyacinth. Fish concentrate in the haven of floating vegetation where they are periodically netted by the ingenious fishermen.

On the other hand, dense growths may restrict the movement and feeding of larger fish, and limit the fishable area of a waterbody. The oxygen-deficient water that may develop in the presence of dense growths, during extended periods when photosynthesis cannot occur, can be fatal to fish. Aquatic plants entangle lures and baits and can prevent fishermen from reaching desirable fishing areas. Control of aquatic vascular plants can be a positive factor in fisheries management (Leonard and Cain, 1961).

The effect of water hyacinth on fish production has been studied (Auburn University, 1971). Plants

were grown on floating frames. In an unfertilised pond they grew very little and the net fish production was the same as in a pond without hyacinth. Fertilised ponds grew hyacinth vigorously and fish production was reduced by 34 and 41% in two ponds. These results would not of course apply to herbivorous fish which would eat the water hyacinth.

AQUATIC WEEDS AND PUBLIC HEALTH

It is of considerable medical and economic importance that the conditions created by dense plant populations and accumulated debris in tropical waters are favoured as breeding sites by vectors of certain diseases. Aquatic vegetation and flotage breaking the water surface enhance mosquito production by protecting larvae from wave action and aquatic predators, and by interfering with mosquito control procedures. Two prominent vectors that take advantage of this are **Anopheles** and **Mansonia** mosquitoes, which carry the parasites responsible for malaria, and rural filariasis and encephalitis, respectively. The plants most frequently implicated in favouring mosquito breeding include water hyacinth, Salvinia, **Nelumbo lutea**, water lettuce, and **Typha sp.** (Sculthorpe, 1967), all of which grow in Guyana. **Mansonia** mosquito larvae and pupae develop underwater on aquatic plants and never surface. They attach breathing tubes to the roots and stems, and obtain oxygen from the air spaces inside. Although **Mansonia** are pest mosquitoes and transmit debilitating diseases, these underwater life stages cannot be controlled by present-day larvicides. Removal of the vegetation is the only method, and it does give almost complete **Mansonia** control. In the Panama Canal Zone, where aquatic organisms are similar to Guyana's, the largest numbers of **Mansonia** have been collected from water lettuce, **Pontederia**, **Scirpus**, and **Luziola** (McLaren, 1967).

The seasonal development of the aquatic plants sometimes appears temporarily related to the habits of the disease vector. Penfound et al. (1945) found, for example, that each year the lotus **Nelumbo lutea** produced its first leaves (each of which forms small pools of rain water) about two weeks before malaria-carrying mosquitoes began to breed. Closer investigation of such relationships could aid the execution of disease-control programmes by the timely removal of weeds.

Certain freshwater snails, such as **Bulinus**, **Biomphalaria**, and **Oncomelania**, are the intermediate hosts of **Schistosoma** which cause schistosomiasis, one of the most critical and insidious diseases of the tropics and subtropics which occurs to a limited extent in Guyana. In the submersed and emergent plant communities of irrigation canals and other waterways, these snails find admirable sheltered habitats with rich supplies of food and suitable surfaces for oviposition. These snails have been found breeding abundantly on water lettuce, and the movement of the floating plants with the snails attached contributes to the dissemination of schistosomiasis (Obeng 1969; Paperna 1969) in Ghana.

Ingestion of fresh, inadequately washed vegetation from stagnant or slow-flowing waters, especially in the tropics, may contribute significantly to the spread of typhoid and other epidemic diseases. The metacercarial stage of the sheep liver fluke can be acquired by man through consumption of aquatic plants (Penfound 1953).

A water surface obstructed by plants reduces aeration, the absorption of oxygen by the water that is the natural method for water purification. Organic pollution in slow-moving streams and canals created by the growth and decomposition of water hyacinth and other aquatic vegetation is similar to that of sewage and industrial vegetable wastes. It has been estimated that the oxygen-depleting pollutional load imposed by one acre of growing water hyacinth is equivalent to the sewage from 40 people (U.S. House of Representatives Document 1957). Aquatic weed control methods which do not remove destroyed vegetation from the waterway may seriously deplete oxygen levels because of the decomposing vegetation.

CHAPTER 3
PHYSICAL CHARACTERISTICS OF AQUATIC PLANTS

Chemical Composition

The composition of aquatic plants has been studied for a considerable time; a water content of over 90% is their overwhelming characteristic. Little (1968) has concluded that the amount of solid in aquatic weeds is typically about 8%. Many samples of freshly harvested water hyacinth contain less than 5%. By comparison terrestrial forages contain 20 - 30% solid, or 2 - 6 times the amount in aquatic weeds. This low level of solid has been the major deterrent to the harvest and use of aquatic weeds as items of commerce. At best, to recover one ton of dry matter, ten tons of weeds must be harvested and handled; for water hyacinth it may require handling 20 tons. Moisture content is critically important when considering utilisation of the vegetation, and it is discussed again in Chapter 6.

Centrally located fibres and air canals give submersed aquatic plants physical properties that are quite different from those of the land plants. Because the plant (approximate specific gravity: 0.8) is lighter than the water which surrounds it, it is to a large extent relieved of the task of supporting the weight of its branches. There is therefore no development of strong fibrous stems. Water hyacinth and other emergent aquatic plants require more skeletal strength in their aerial parts and have significantly more fibre and a much more spongy structure than do most submersed plants.

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

The chemical composition of a species of aquatic plant is markedly affected by the aquatic site in which they grow.

Nitrogen Content. The protein content of a select few aquatic weeds has been measured by the Kjeldahl procedures used for forage analysis. Generally the solid matter of the plants contain between 10 and 26% crude protein (on a dry matter basis). Water hyacinth averages between 10 and 16% protein, water lettuce about the same, and submersed weeds such as **Hydrilla** and water milfoil average 14 - 18%. As a general rule it can be stated that aquatic weed species contain considerable crude protein (on a dry weight basis). For water hyacinth, water lettuce, and **Hydrilla** species, Boyd (1969) has concluded that at least 80% of the total nitrogen was in the form of protein.

The individual amino acids are present in quantities similar to those reported for many land forages of similar crude protein content. But the levels of methionine and lysine, generally considered the limiting amino acids in plant proteins, are lower than in certain high-quality crop plants. That this may not be a general rule, however, is suggested by other workers (Taylor and Robbins, 1968) who report a percentage of lysine in water hyacinth equal to that found in milk.

Mineral Content. Ash, "other extract", and available carbohydrate levels are generally high in aquatic plants. Ash contents are higher than in land forages because silt and sand can deposit thickly on the vegetation. Mean values range from 17.0 to 27.6%, but are dependent on the waterway turbidity and dissolved mineral content.

Although silt can be deliberately washed from laboratory samples it probably will be present in plants harvested for utilisation, and so from a practical point of view represents a portion of the inorganic fraction of the plants.

Five elements – phosphorous, calcium, potassium, magnesium, and sulphur – generally comprise most of the ash of plants. Samples of water hyacinth

and water lettuce in Guyana (Bates, 1973) have been measured as:

Water Hyacinth		Water Lettuce
Total Ash: 25.5% of dried vegetation		29% of dried vegetation
Phosphorour (as P_2O_5)	3.2%	1.8%
Potassium	20.3	15.4
Calcium	3.1	9.2
Magnesium	4.3	11.8
Sulphur (as SO_3)	4.4	3.3
Other Components		
Aluminium	18.6	10.3
Iron	5.2	2.7
Sodium	6.6	4.7
Manganese	0.3	3.3
Chlorine	18.4	18.8
Sand	20.00	13.00

Samples of water hyacinth and **Hydrilla** have been compared against a terrestrial forage, coastal bermuda grass (Stephens, 1972). Concentrations of phosphorous magnesium, sodium, sulphur, manganese, copper and zinc were quite similar. However, **Hydrilla** had several-fold greater concentration of ash, calcium, potassium, and sand-silica than either water hyacinth or coastal bermuda grass. The aquatic plants were very high in iron compared to the land forage.

Miscellaneous. Aquatic plants can have carotene and xanthophyll pigment levels equal or greater than terrestrial grasses such as alfalfa. Perhaps the best studied species is water milfoil, which may contain 300 - 500 mg/lb (Koegel et al., 1972). Water milfoil and other submerged weeds have been proposed as commercial sources of these pigments which are necessary ingredients of poultry rations. The biological effectiveness of water milfoil xanthophyll in pigmenting egg yolks has been reported (Couch et al., 1964).

Traces (but no determinable quantities) of pesticides have been found in aquatic plant samples collected in the U.S. (Shirley and Easley, 1970). This is not likely to be a concern in Guyana unless the waterway has been recently treated with herbicides or insectides. Also traces of cyanide, oxalate, nitrate have been found, but at levels not grossly different from terrestrial grasses, and no evidence of toxicity to mice, sheep, or cattle has been found in water hyacinth or **Hydrilla**. (For more detail see Chapter 6).

Productivity of Aquatic Plants

The per-acre yield of aquatic vegetation often exceeds that of terrestrial plants (Westlake, 1963). Submersed freshwater plants may attain 32 - 52 m.tons/acre in warmer climates (the most productive communities of all are likely to be found in the tropics).

Water hyacinth is thought to be exceptionally productive (Bock, 1969). Westlake (ibid.) stated that "if it were possible to devise cultivation techniques which would enable plants to grow all the year at the rate normally attained for only short periods in their seasonal cycle, much greater annual productivities, up to 150 m.t. per hectare per year* might be attained. **Eichhornia crassipes** might be a suitable plant for such cultivation.

Water hyacinth populations increase rapidly; in one experiment two parent plants produced 30 offspring after 23 days, and 1200 at the end of four months (Holm et al., 1969). In Guyana a six-month growth has been measured at 55 tons per acre of hyacinth and 30 tons per acre of water lettuce (Bates, 1973). It has been suggested that because of uniform seasonal temperatures 100 tons of hyacinth could be grown per acre per year in Guyana. This represents a yield of some 7 tons of dry vegetation per acre per year, and 4 tons of vegetation per acre per year from water lettuce. These figures might well prove low because Knipling et al., (1970) report stands of 188 tons of fresh hyacinth per acre containing 10.9 tons of dry matter. They further report weight gains of 4.8% per day. Steward (1970) estimates hyacinth yields of 14.7 to 67 tons of dry matter per acre a year, depending on environmental conditions.

Nutrients. Chemicals necessary for the growth and reproduction of rooted or floating flowering plants are considered to be nutrient chemicals. Terrestrial plants obtain nutrients from soil, and aquatic plants absorb theirs from the water in which they grow (as well as from the soil if they are a rooted variety).

* 150 m.t. per hectare = 60.7 metric tons per acre
= 66.8 tons/acre

Not all these chemicals are known, but those identified are classified as macronutrients, trace elements (micronutrients), and organic nutrients. The macronutrients are calcium, potassium, magnesium, sodium, sulphur, carbon, and carbonates, nitrogen and phosphorous. The micronutrients are silica, manganese, zinc, copper, iron, molybdenum, boron, titanium, chromium, cobalt, and perhaps vanadium. Examples of organic nutrients are biotin, vitamin B_{12}, thiamine, and glycylglycine.

Waterways over-enriched with nutrients are termed **eutrophic**. Eutrophication leads to dense growths of aquatic plants because of the abundance of nutrients. In the U.S. man's activity has increased nutrients in waterways, causing aquatic plants to increase to nuisance proportions in waters where natural fertility levels are insufficient to maintain dense populations (Lind and Cottam, 1969). This may also be true in the densely populated and heavily farmed coastal regions of Guyana. In the savannahs and mountain regions, nutrients added by man are less of a problem, but natural fertility combined with an ideal water temperature may support nuisance growths.

The nutrients are absorbed from the water by the plants and incorporated into their mass. Nutrients incorporated in this way are removed from the waterway proper, and this absorption of dissolved pollutants into harvestable vegetable matter gives a mechanism for nutrient recovery and for reducing eutrophication.

In experiments, water hyacinth proved very effective in absorbing nutrients from eutrophic waters (Boyd, 1970; Yount and Crossman, 1970; Peterson, 1971; and Miner et al. 1971), and, since water hyacinth can produce a standing crop of hundreds of tons per acre (tens of tons dry weight), this plant might in practice become useful for removing excess nutrients if economic methods for harvest and disposal are found.

Researchers in Iowa (Miners et al., ibid.) feel that large-scale harvesting from natural waters can be expected to reduce the productivity of those waters, and probably reverse the trend toward eutrophication especially in polluted waters. These researchers have grown water hyacinth on lagooned sewage from a pig farm and found that the plants grow rapidly. Even under the short growing season in the Northern U.S. the plants removed nitrogen at the rate of 500 lb. per plant-covered area of water. "Hyacinth lowered nitrogen, phosphorous, and organic levels to the point that the liquid could safely be discharged into streams, or used for irrigation, without contaminating ground water."

Water hyacinth and **Ceratophyllum demersum** have been grown experimentally on city sewage One report (Schulze, 1966) states that beside showing a high removal of nutrients and suspended solids, the aquatic plant also proved to be very effective in the removal of odour, and that in contrast to the incoming sewage, the effluent was sparkling clear. Water hyacinths grow rapidly under these conditions and produce large plants, high in protein.

With a maximum stand of water hyacinth (to use Knipling et al.'s 17 tons dry weight per acre), the following amounts would be removed by one acre of plants if harvested once a year.

Element		Lb. removed
Carbon	-	15,224
Potassium	-	1,067
Calcium	-	646.8
Nitrogen	-	627
Magnesium	-	272.8
Sodium	-	169.4
Manganese	-	77
Phosphorous	-	59.4
Iron	-	50.6
Zinc	-	6.6
Copper	-	0.66

CHAPTER 4

BIOLOGICAL CONTROL

Biological control agents promise to become a powerful tool in the aquatic weed control arsenal. Microbes, competitive plants, snails, insects, fish, and other vertebrates are being investigated in many laboratories worldwide for use as agents to control rampant aquatic weed growth. However, this field has been largely neglected until recently, and examples of satisfactory biological control of aquatic weeds are still few compared with those of terrestrial weeds.

Several of the more serious aquatic weeds exist in uniform stands, i.e., a virtual monoculture. They also are in a relatively more constant environment (with regard to changes in temperature and humidity) than occurs in most terrestrial situations; therefore, organisms released to control aquatic weeds may have better conditions to develop the type of population explosion necessary to decimate its host than those for terrestrial weeds.

Biological control will seldom eradicate the weed, but this is not the measure of success. In nature, a balanced growth of aquatic plants is maintained by plant-feeding insects, diseases, nematodes, fungi, bacteria, viruses, fish, snails, and mammals. Biological control agents are selected to tip this balance and reduce the plant's vigour but not necessarily to destroy it completely. Any damage or reduction in vigour may render the weed more prone to attack by the other plant-eating organisms. For example, water lettuce plants frequently collapse rapidly and sink because of the secondary attacks following minor damage from insects that feed on it.

Biological control will not be cheap and simple; it is complex and challenging. The organisms will undoubtedly have to be managed, whether they are insects, microbes, fish, or mammals. For example, they may have to be released at a season when they have the greatest potential to establish a resident population, and even then may require help in getting established. Their numbers in the field may have to be checked periodically and replenished if necessary. Success will require the services of technicians well trained in relevant aspects of biological science.

Before a biological control agent is introduced into a new area it must be thoroughly investigated. It must not be released if it will attack desirable plants or animals. In Guyana, in particular, care must be taken because of the importance of rice which itself is an aquatic plant.

This report emphasises potential biological agents that not only control aquatic weeds, but at the same time provide meat and food.

Fish

Certain species of herbivorous fish have been studied by biologists for use in controlling excessive aquatic weed growth. Fish control aquatic weeds in different ways and are classified as:

1. **Grazers** that ingest stems or foliage or both, e.g. **Tilapia zillii** and **Ctenopharyngodon idella.**
2. **Mowers** which devour only portions of aquatic plants, primarily the bases of tender shoots, e.g. **Metynnis roosevelti** and **Mylossoma argenteum.**
3. **Roilers** that stir the bottom sediments while foraging for food or preparing nests, e.g. **Cyprinus carpio.** The colloidal soil and fine debris that are kept in suspension by the fish, or settle to coat the foliage, reduce the light needed by the weeds for photosynthesis and growth.

Tilapia. Hawaii's sugarcane, like Guyana's, is often planted in drained swampland. In 1957 it was reported (Hee) that one 3,500 acre sugar estate cut costs for aquatic weed control to virtually nothing by using Tilapia.

Tilapia are prolific; in theory, one pair can lead to 1,500,000 offspring in a year. They thrive in fresh and brackish water, clear or muddy. On the

Hawaiian sugar estate 75,000 fish, each 3-4 inches long, were released into the reservoirs and distributed themselves via the irrigation channels. Weeds were cleared with chemicals before the fish were released and, given this start, the fish were able to keep the regrowth at bay. The initial cost was some $3,000 using fish, compared with a $5,000 annual cost for control by herbicides, but the cost for weed clearance in two subsequent years was quoted as being a total of $25.

White Amur. The species of vegetarian fish currently attracting most attention is the white amur or Chinese grass-carp, **Ctenopharyngodon idella Val.** While not cleared for unrestricted distribution in the United States (it is banned in some States which fear it might reproduce and become a pest itself) it is under study in certain ponds and lakes (Bailey and Boyd, 1970). It is being stocked widely in Europe (Krupauer, 1971; Robson, 1971), Asia (Mehta and Sharma 1972), and Fiji (Huges, 1971), and appears to acclimatise to tropical waters.

The white amur is a grazer (Yeo and Fisher, 1970) and consumes a wide variety of submersed and floating aquatic vegetation (Avault et al., 1966 and Singh et al., 1969). Individual fish are reported to grow as large as 110 pounds (Nikolsky 1956). The white amur will grow in clear to turbid waters, in saline waters up to 10,000 ppm (Doroshev 1963) in oxygen levels as low as 0.5 ppm (Stevenson [illegible]5). Growth rates under ideal conditions are as much as 10 grams of flesh per day (Nikolsky 1956).

Taste tests indicate that out of seven commonly marketed fish the white amur rated second best (Bailey 1972). Okoniewska and Okoniewski (1968) found the crude protein of the white amur to be 17.9% in wet mass and 77.2% in dry mass.

The white amur can be caught by bait-fishing, although it is quite wary (Bailey 1972). Gill and trammel nets are more effective.

Threat of uncontrolled distribution of the amur by natural reproduction is unlikely as the spawning requirements of the fish are very critical, including: (a) rising water (2-4 feet over normal) and temperature (Inaba et al., 1957), (b) the eggs must be suspended in clear floating water for at least 15 to 35 hours (Bailey 1972), and (c) newly hatched young need to lie in quiet water for at least 24 hours to survive. It is doubtful whether these criteria are met in Guyana's water systems.

This species has spawned in nature in only a few areas outside its native Siberian and East Asian homeland. This may offer an advantage initially, as the effect of the fish on native fauna and flora can be studied in the field with little risk of its becoming a pest itself. The fish can be spawned artificially by injecting selected hormones (Bailey and Boyd 1970).

Silver Dollar Fish. The South American fish, **Metynnis roosevelti** and **Mylossoma argenteum**, hold a promise to control certain submersed aquatic weeds (Yeo, 1967). These commonly are referred to as 'Silver Dollars'. Generally the tender shoots of submerged weeds 3-12 inches long are the most palatable to them. Silver Dollars are active grazers at the warm temperatures found in Guyana, and they are probably more appropriate to Guyana than to temperate countries where heated over-wintering facilities will be needed.

Manatees

During the eras of exploration and colonisation, voyagers in the Caribbean area were well aware that manatee flesh brought a welcome and nourishing change from shipboard diet. According to one early report (Esquemeling 1678), expeditions put in to some South American harbours specifically to stock up on the meat of the manatee, **Trichechus manatus Linnaeus.** Today in South America this species is still found in the rivers and coastal regions of Colombia, Venezuela, Guyana, Surinam, French Guiana, and northern Brazil.

The manatee is capable of living both in freshwater and marine environments and is often observed in estuaries. Strictly vegetarian, manatees eat a wide variety of aquatic plants but seem to prefer submerged, floating, and emergent plants, in that order (Allsopp, 1969; Hartman, 1971). Lacking incisor or canine teeth, the manatee relies on protrusible lips and bristles to pull vegetation into its mouth where it is ground by the molars. In Guyana and Florida manatees have been known to consume aquatic vegetation of the following genera:

Submersed:	**Cabomba, Elodea (Anacharis), Hydrilla, Utricularia, Najas, Myriophyllum, Potamogeton, Vallisneria, Ceratophyllum, Ruppia, Nitella, Syringodium, Thalassia, Chara, Ulva.**
Floating:	**Eichhornia, Salvinia, Azolla, Pistia, Victoria, Lemna, Paspalum Neptunia, Hymenachne.**
Emergent:	**Montrichardia, Typha, Sagittaria, Spartina, Ipomoea, Panicum, Leersia, Alternanthera, Nymphaea, Nelumbo, Nelumbium, Luziola.**

Manatees have been maintained in captivity in Guyana for almost a century and have kept ornamental

pools in the Botanic Gardens in Georgetown clear of vegetation (Allsopp, 1960). The effectiveness of manatees as weed clearers in Guyana* has been recorded (Allsopp, 1960; Anonymous, 1962):

> Two manatees 7½ feet long cleared a canal in the Georgetown Waterworks (22 feet wide and 1,600 yards long) in 17 weeks. Weeds cleared: **Cabomba, Elodea, Leersia,** and **Utricularia.**
>
> Four manatees cleared the Ruby/Bocrasirie distributary (surface area 7.6 acres) of **Cabomba aquatica, Nelumbium speciosum, Paspalum repens,** and **Utricularia foliosa.**
>
> Four manatees could not eat all the **Cabomba, Nelumbium,** and **Luziola spruceana** in the Wales/Georgia distributary (surface area: 19 acres).
>
> Two manatees cleared the Mainstay escape canal (surface area: 7.75 acres) of **Cabomba, Luziola,** and **Hymenachne amplexicaule.**
>
> Two manatees found the weeds in the Craig distributary (1.5 acres) insufficient and had to be transferred elsewhere.
>
> Four manatees kept the Craig distributary (conservancy to regulator 6.8 acres) clear, but **Paspalum vergatum** persisted at the fringes.
>
> Four manatees cleared the Garden of Eden distributary (12.4 acres) though regrowth of **Paspalum repens** was very rapid.
>
> Three manatees kept the Black Bush Polder channels (5 acres) free of aquatic plants.

All told, more than 120 manatees have been introduced with varying success in irrigation canals, reservoirs, and drainage systems in Guyana.

Advantages of Manatees as Agents of Aquatic Weed Control:

1. Manatees are docile, unobtrusive, and harmless to man.
2. Manatees are voracious feeders, consuming as much as ¼ of their body weight per day. An adult manatee, exceeding a half ton in weight and 10 feet in length, undoubtedly consumes more than 200 pounds of wet vegetation each day.
3. Manatees are remarkably unselective in their choice of food. Although they prefer succulent aquatics, if denied this they will consume almost any water plants.
4. Manatees adapt readily to confinement, provided they are assured an adequate food supply.
5. Manatees can survive in water that is fresh or saline, acid or alkaline, turbid or clear. Water temperature is not a limiting factor in Guyana.
6. Despite their size and weight, manatees are relatively easy to transport. They tend to remain passive and immobile out of water, but care has to be taken to prevent them from rolling on their backs.
7. Manatees are a potential source of protein.

Disadvantages of Manatees as Agents of Aquatic Weed Control:

1. Manatees are highly vulnerable to poaching and vandalism. Their protection in a given waterway may demand constant surveillance.
2. Manatees have never been known to breed in either captivity or semi-captivity. The reasons for this failure are unknown, but are perhaps related to some nutritional deficiency or imbalance, or conceivably to a state of stress induced by confinement.
3. Although they apparently lack a breeding season, manatees have an exasperatingly slow reproductive rate. The gestation period is not known with certainty. An incident in Florida suggests a gestation of approximately 13 months (Hartman 1971). The postpartum-preconception interval for manatees evidently varies from one to two years, and is regulated, by the time required to wean a calf. Cows with calves come into oestrus but may not be impregnated. Barring infant mortality then, cow manatees probably breed no more than every two years and more likely every 2½ to 3 years. (Hartman 1971). Observations of the size, growth rate, and behavioural attributes of juveniles suggest that sexual maturity is not attained before three and possibly as late as five years. (Hartman 1971).
4. There is no data on the life expectancy of manatees in the wild. One author thought that it might exceed 50 years. A manatee was confined in a pond by Spanish colonists for 26 years, and another, in Florida, born 25 years ago is still alive.

* Also in Florida by Sguros (1966), where five manatees cleared a canal ½ mile long and 25 feet wide in three weeks. Weeds cleared: **Utricularia, Najas, Sagittaria,** and **Typha.**

5. In navigable waterways manatees can be fatally wounded by the propellers of power boats. Precautions must be taken to prevent manatees from drowning in culverts, sluices, or lockgates. Manatees should not be introduced in waterways less than 4 feet in depth; they prefer access to depths of 6 feet or more.

Manatees are on the international list of endangered species. They appear to have no natural enemies other than man. Their rarity presents additional problems and expenses associated with their capture. Locating manatees for purposes of capture can be facilitated by aerial reconnaissance.

The manatee will never be a universal aquatic weed control agent, but its use in local small-scale weed clearing operations is feasible. Manatees may be used for weed clearance as a complement to other conventional methods. For example, manatees may be used only to remove succulents while other means are employed to clear fibrous and unpalatable plants; manatees may be used to keep down regrowth after a weed infestation has been reduced by other methods. Manatees may be unable to control exceptionally large masses of vegetation and periodic removal of the excess by alternative means may be required.

Hopes for large-scale utilisation of manatees as a source of meat are, at this stage of our knowledge, unrealistic. Too little is known about the population dynamics of manatees. Physiological and reproductive studies are needed to understand more fully the animal's breeding potential and, if possible, to accelerate it. Superovulation, hormonal stimulation, and artificial insemination have been proposed as means toward this end. (Allsopp 1969). It may also be possible to speed up the growth rate of manatees by, for example, feeding them dewatered aquatic plants rich in nutrients.

Other Vertebrates

Turtles. Man has always relished turtles, and it is likely that almost every species has at one time or another satisfied the human appetite. Certain vegetarian turtles may also prove useful supplements to aquatic weed management programmes. One set of experiments in Florida (Yount and Crossman, 1970) showed that two small "sliders" (**Pseudemys floridana peninsularis**) devoured 50 lbs. of water hyacinth (some of it crushed) in six days. Healthy hyacinth was not attacked, but after the animals had learned to eat the crushed plants they would then consume healthy ones. Allen (1938) and Carr (1952) also report turtles consuming water hyacinth. A number of South American herbivorous turtles are on the Endangered Species List. Investigation of the economic benefits they might bring in support role to weed control programmes might eventually provide an economic incentive for their husbandry, and remove threat of their extinction.

Terrestrial Herbivores. Many wild animals play an important role in weed control in their native habitats. They have been little considered for release elsewhere, and indeed probably have no place in conventional weed control projects. Nevertheless, seen in the light of a self-supporting cottage-farming activity, they might also contribute to weed control.

Grazing of cows, water buffalo, goats, sheep, donkeys, etc., could be promoted in Guyana to control vegetation along shorelines and canal banks if erosion of the adjoining land is not extensive. Managing the plants to maximise species favoured by the animals – possibly by deliberate planting or by using herbicides that selectively kill undesirable species – should be considered.

An example of this method in action was witnessed by the panelists at the Bel Air Dairy in Georgetown. Cattle routinely enter a canal and graze water hyacinth. Though they grazed only the leaves, and vegetation remained covering the water surface, the hyacinth's reproduction appeared much reduced and the mat was not spreading into the open water downstream.

Though grazing animals can restrict the spread of floating and emergent aquatic plants, they do not impede the spread of less palatable plants. Also, enough animals must be used to ensure that the succulent plants being consumed do not overmature to an unpalatable state.

The South American coypu or **nutria**, native to Guyana, has been suggested as a useful animal for control of aquatic weeds. It has been widely disseminated as a fur-bearing animal in North America and Europe, and released in parts of Africa. The relatively low value of its pelt, the damage caused by its burrowing activities, and its omnivorous feeding habits should be considered before its further deliberate dissemination either for weed control or for fur-farming is undertaken.

Insects

Insects affect aquatic plants adversely when juvenile or adult stages feed on them. This reduces the quantity of vegetation and also wounds the plant and opens it to attack by pathogens, fish, turtles, and other organisms.

The insect life living on aquatic plants is now being studied worldwide to find species that most

efficiently destroy problem aquatic weeds. The insects are being studied particularly in the countries where the plant is native, for there the insects have had the maximum time to develop predation efficiency. Insect species that can control specific aquatic plants in the laboratory are known, but few large-scale field programmes have been conducted (Bennett, 1972).

The weevil **Neochetina eichhorniae**, collected off water hyacinth in Argentina, has been reared and released in the United States. The same species, as well as **Epipagis Albiguttalis**, has been sent to India and Zambia to test whether they can help control water hyacinth infestation there. A programme using the South American flea beetle **Agasicles hygrophila** to attack **Alternanthera philoxeroides** in the U.S. is demonstrating the effectiveness of using insects for aquatic weed control (Maddox et al., 1971).

Current insect candidates (and one mite) for water hyacinth control (all collected from South America) include:

Neochetina bruchi	Hulst	weevil
Neochetina eichhorniae	Warner	weevil
Orthogalumna terebrantis	Wallwork	mite
Acigona infusella (=ignitalis)		stem borer
Epipagis albiguttalis	Hmps.	stem borer
and **Cronops sp.**		

These insects are in various stages of clearance for release on aquatic weeds in the U.S. and elsewhere; **N.eichhorniae** was released in mid-1972. All of these except the **Neochetina sp.** are known to occur in the coastal areas of Guyana, (Bennett and Zwolfer, 1968), and **N.eichhorniae** has been found in the Rupununi area.

Surveys in the United States indicate that water hyacinth is attacked by several insects and the mite **Orthogalumna terebrantis**, but, with the exception of the mite, they are not sufficiently host-specific to permit introduction elsewhere.

Current candidates for control of **Salvinia** species are:

Paulinia acuminata		grasshopper
Cyrtobagous singularis	Hulst	leaf miner
Samea multiplicalis	Guenee	moth

All of these occur natively in coastal Guyana.

Host-specificity studies have been carried out on these (Bennett 1966). While **C.singularis** is specific to **Salvinia**, **P.acuminata** is known to feed on several other botanically unrelated aquatic weeds, including water lettuce. **S.multiplicalis** develops readily on water lettuce also and has been reared from water hyacinth. Field observations and laboratory studies indicate that all three are restricted to an aquatic environment and do not attack terrestrial economic plants. These three insect species have been shipped for release in Africa and for further study in India.

There are as yet no studies of insects with potential to control Guyana's other aquatic weeds such as **Cabomba, Utricularia, Nymphaea sp. Paspalum repens**, etc.

Snails

A large freshwater snail **Marisa cornuarietis** has freed small ponds in the southern United States and Puerto Rico from submersed weeds. **Marisa** has been used as food in Puerto Rico; it carries no disease that can be transmitted to man, and its habit of feeding on other snails actually makes it a biocontrol agent for disease-carrying snails. A major disadvantage is that it may feed upon certain desirable plants growing in the water, such as rice and watercress, though it does not eat emergent rice (Yeo and Fisher, 1970).

A second freshwater snail, **Pomacea australis**, widely distributed in Brazil, shows promise as a biological control agent for both submersed and floating aquatic weeds. Although its wide host range may make it undesirable in many areas, Silva (1960) utilised it to combat submersed pond weeds in Brazil.

Pathogens

Research on viruses, fungi, bacteria, nematodes, etc., that injure aquatic plants is still in the laboratory stage, and no organism is yet ready for release for aquatic weed control. Yet this method offers a challenging and potentially powerful method, because many candidate microbial organisms are specific and will attack the target weed species only. Thus, pathogens could provide aquatic weed control on a "prescription basis". Many organisms affecting a wide variety of host plants have been reported. The extent that they (and still unreported organisms) adversely affect aquatic weeds needs to be investigated (see Wilson, 1969, for a review).*

Blue-green algae have been successfully controlled by a virus in large-scale experiments in sewage disposal pools (see Wilson, ibid.), and a virus may have been responsible for the reduction of hundreds of thousands of acres of water milfoil in the Chesapeake Bay Region of the U.S. (Bailey, 1970).

* Recently, laboratory and quarantine facilities for the study of pathogens on aquatic weeds have been established at the University of Florida.

Once selections and mass-rearing are complete, pathogens could be dispersed in the field using the personnel and spray equipment currently used for herbicides or insecticides. In most cases they can be handled as a powder and stored for months at a time. The mass-rearing too is likely to be adaptable to conditions in Guyana, and could reduce dependence on imported sprays.

While no recommendations can be made for the immediate control of aquatic weeds using pathogens, developments elsewhere may alter the position within a few years. In the meantime, an inventory of the pathogens already attacking aquatic weeds in Guyana could lay the groundwork for using exotic pathogens when they become available.

Competitive Displacement

When one species replaces another because of its vigour or improved ability to survive, this is known as competitive displacement. For example, water hyacinth in many waterways outside its South American home has displaced the native aquatic vegetation by superior competition for space and food resources.

In theory, this process can be deliberately manipulated to displace a harmful aquatic weed by harmless (or less harmful) species. This is done either by introducing a harmless foreign species that has a competitive edge, or by manipulating the waterway to favour a harmless species already present. This concept is exemplified by: (a) the fish farmers in the southern U.S. who fertilise ponds to the point where blooms of algae become so dense that submerged aquatic weeds get no light and die (Davison 1947); and (b) the Hawaiian fish farmers (Alikunhni 1952) who, faced with algae-filled ponds, introduced duckweed (**Lemna minor L.**) which covered the water surface, so that the algae got no light or air and disappeared in six days.

Recently, submerged aquatic plants that grow only 1 - 2 inches high have been deliberately planted on canal bottoms to displace the tall weeds that retard water flow (Yeo and Fisher 1970). This "underwater carpet" technique is new and novel, but is well worth considering for Guyana because of its potential low-cost and maintenance-free nature. The "carpet" plants so far studied in California include three spikerushes **Eleocharis coloradoensis** (Eritt.) and Gilly, **E.acicularis** (L.) R & S, and **E. parvula**, as well as **Tillaea aquatica L.**

The spikerushes are perennials which can survive continuous submersion or repeated de-waterings. They have fine rhizomes and fibrous roots which form dense mats of sod, so that little, if any, soil is left open for problem weeds to root in.

As mats of the spikerushes develop and spread, neighbouring submersed aquatic weeds are displaced and are prevented from regrowing. In California, a small stand of spikerush was observed on a canal bank in 1966. By 1969, it had covered 1 1/8 miles of the canal which were completely "weed" free, while large areas of the rest of the canal were infested with tall problem weeds (Yeo 1972). The turf-like sod formed by the mats can be harvested and replanted to establish new stands. Spikerush sod is easy to handle and store, and will survive if canals are drained. Indeed, even if the soil dries out, spikerush seeds and tubers survive and will re-establish the plants with returning moisture.

Herbicides that kill nuisance aquatic weeds without affecting the spikerushes are available, and these can be used to increase the competitive edge of the latter while it is becoming established.

CHAPTER 5

CHEMICAL CONTROL

Aquatic weed control using herbicides is by far the best known technique, and in the past 30 years has been used to the virtual exclusion of all others. Little needs to be added in a report as general as this one. Organisations exist that provide specific advice,* and a massive literature is available.

Perhaps unfortunately, all pest controls that spray synthetic organic chemicals into the environment are today in a state of crisis. The very properties that made these chemicals so useful – long residual action and toxicity for a wide spectrum of organisms – have brought about serious environmental concern.

Nevertheless, herbicides will always have their place in the arsenal of aquatic weed control methods. Many important weed infestations lie among trees and stumps that have been partially submerged, and these may be so numerous as to be a barrier to any form of weed harvest. In other cases, small infestations may best be eliminated by using chemicals when harvesting is inappropriate and biological controls too slow.

A good deal is known about the susceptibility of important water weeds to various candidate herbicides. But many herbicides are so expensive, particularly in terms of foreign exchange, as to greatly restrict their use. 2,4-D is a relatively cheap compound and is fortunately effective against water hyacinth. But it still must be used at considerably higher rates than is normally sufficient for control of broad-leaved weeds in crops.

Surface weeds can be sprayed with herbicide directly, but to treat submersed weeds, the whole waterway must be treated. Candidate chemicals for these are more limited and, in particular, the risk of fish kills limits the choice and the concentration to be used. Many different kinds of formulations, including wettable powders, slow-release formulations, granular formulations, and invert emulsions have been developed to better target the herbicide on to the vegetation without polluting too much of the water.

In Guyana many herbicides have been evaluated. The two major ones used at present are (a) 15% pentachlorophenol emulsion concentrate (PCP); and (b) triazine herbicides (Bates, 1973). The former is normally used for control of underwater "mosses" i.e. **Cabomba**, etc. It gives at least six months control. PCP at very low concentrations (e.g. 1:500,000) has given 100% control in middle-walk and cross-canals, probably because the water is static.

Triazine herbicides (at 0.5-1.0 PPM) have been particularly effective against the hard-to-kill **Paspalum repens**.

It is unfortunate that PCP, even at the low concentration used for aquatic weed control, is toxic to fish life, as fish add to the diet of estate workers and some fish eat mosquito and midge larvae. Large numbers of fish (including specimens up to 18 inches in length), are brought to the surface of PCP-treated sidelines only an hour or two after spraying. These are frequently collected by the spraying gang. It has been observed that after a time fishes, particularly mosquito-eating fish such as **Lebistes sp.**, once again appear in treated canals.

In treating cross-canal and middle-walks, the concentration of PCP concentration of 1:2500,000 is so low as to be harmless, although the water does have a very faint "phenolic" taste for a day or so after treatment, about which there have been some complaints. For these reasons PCP is being phased out.

* E.g. the A.R.C. Weed Research Organisation, Begbroke Hill, Yarnton, Oxford, England.

SUGGESTED* HERBICIDES FOR AQUATIC WEED CONTROL IN GUYANA

Chemical	Rate of Application as Active Ingredient	Area of Use and Limitations
2,4-D Amine[a] (Amine salt of 2,4-dichlorophenoxyacetic acid)	2 to 4 lb/A per 100 gal. diluent	Controls water hyacinth, duckweed, salvania, water lettuce. Do not use treated water for potable supply or irrigation. Do not apply near sensitive crops. Spray foliage.
Diquat (cation)[a] (1,1′-ethylene-2,2′-dipyridylium dibromide)	1.0 to 1.5 lb/A per 150 to 200 gal. diluent	Controls duckweed, water hyacinth, water lettuce. Do not use treated water for potable supply or irrigation for 10 days. Spray foliage.
Dichlobenil[a] (2,6-dichlorobenzonitrile)	10 to 15 lb/A apply as granule	Controls rooted plants e.g. **Utricularia, Cabomba, Elodea.** Apply to exposed soil or through static water (before weeds mature). Do not use treated water for 90 days in potable and irrigation water.
Fenac[a] (2,3,6-trichlorophenyl acetic acid)	15 to 20 lb/A	Controls same weeds as above. Apply to exposed soil. Do not use treated water for potable supply or irrigation.
Dalapon[a] (2,2-dichloropropionic acid)	20 to 30 lb/A per 100 to 400 gal. diluent	Controls grasses and grasslike plants floating or rooted along water's edge. Add wetting agent. Spray before plants mature.
Copper sulphate[b] Pentahydrate	4.0 ppm (pentahydrate)	Controls algae.

* Suggested by N.A.S. panelist R.R. Yeo.
[a]Does not harm fish.
[b]May harm fish. Most species are tolerant to recommended dosage.

CHAPTER 6

AQUATIC WEED UTILISATION

Bodily removing aquatic weeds from the waterways and selling them to defray the cost of removal is an appealing concept, because it may lead to a self-sustaining or low net-cost system of management. Inherent in this approach are all the advantages of waterways free of vegetation, together with those of an extensive vegetation resource (especially advantageous in Guyana where forage and fertiliser are in short supply).

Some advantages to Guyana when compared with other approaches to water-weed management are:

- possible (but not yet proven) low net cost; relatively slight requirement for foreign exchange when compared (over a period of several years) to chemical control;
- low requirement for skilled manpower but probable ability to provide jobs for unskilled workers;
- compatibility with fish production (i.e. harvesting can be controlled to leave enough vegetation to maximise fish production);
- safety with respect to terrestrial crops growing near the waterway;
- rapidity with which it could be introduced, and its ability to quickly and predictably remove weeds from limited, specified areas (of biological controls);
- removal of nutrients and detritus from the waterway.

Processing

As noted previously, aquatic plants typically contain between half and one-sixth the percentage of solids in land grasses.

The problems this causes are exemplified by the situations where:

- If 100 lbs. of water hyacinth were fed in a fresh state, the animal eating it would have to excrete 95 lbs. of water which is likely to use up more energy than he gets from the remaining 5 lbs. of solid;
- For every 100 lbs. of aquatic plants laid out to sun-dry, over 90 lbs. of water must be evaporated, and this must occur rapidly enough that moulding and bacterial decomposition do not occur;

Transporting the plants is difficult both because of their extreme bulkiness and the high percentage of water that must also be transported. Over and above the low specific gravity characteristic of submersed floating weeds, the tangled matted growths that occur in nature make them even more bulky and hard to handle; little wonder then that most approaches for aquatic weed control in the past have de-emphasised handling.

In industry numerous processes are commonly used to reduce volume and remove water. Some processes which are effective, reasonably efficient, and may be economical for aquatic weeds have been selected by aquatic weed researchers.

The pioneering work in processing aquatic weeds for agricultural utilisation was initiated in 1967 by Hiller and Vietmeyer (Vietmeyer 1968), and has been developed since at the Universities of Florida (Bagnall 1970; Bagnall et al., 1971) and Wisconsin (Bruhn et al., 1971; Aboaba et al., 1971; Koegel et al., 1972). Although experimental in nature, the success of these programmes has spawned industrial interest (Wahl 1972), in converting experimental units to commercial ones.

Reduction of aquatic plants by chopping, e.g. in a conventional forage chopper, reduces volume to less than ¼ of its original value, substantially improves flow characteristics for handling and pressing, increases

reaction rate in composting, and eases dispersion when the plants are used as soil additives. Production rates in standard choppers are usually substantial and power requirements modest. Alternative methods of reducing the volume of fresh aquatic plants are crimping, crushing, or flail-chopping.

Some of the moisture associated with aquatic weeds is surface moisture and some is loosely contained in the plant's vascular system. These account for 50% of the total water in water milfoil and this water can be removed with relatively small losses of nutrients by pressing with rubber-covered rollers (Bruhn et al., 1971). The press water can be returned directly to the waterway without causing pollution. Rollers have not yet been devised which will satisfactorily press water hyacinth, as the hard core of the plant will not pass through easily

Mechanical dewatering not only reduces the water content, but produces a relatively noncohesive product which is easily handled and allows passage of air, heat, and moisture during drying. A relevant bibliography (305 references) on dewatering has been published (Fomin and Bruhn 1972). Only roller presses and screw presses have been tested as means of dewatering aquatic weeds.

from copra. While these machines are initially quite expensive and the power consumption is high due to internal friction on the material being dewatered, their effectiveness, availability, capacity, and reliability justify their investigation for aquatic weed dewatering.

Tests ran on commercially available screw presses (Bruhn et al., 1971) showed 72% water removal and 20% dry matter loss from water milfoil. Bagnall (1972) reports 75% water removal and 15% dry matter loss from water hyacinth.

Accumulated experience has shown that well-designed presses can remove 80% of the water from weeds, and this juice can contain 16% of the plant's solid matter, 15% of the protein, and 40% of the ash (comprising much of the silt that adheres to the plants). Ranges of performance on water hyacinth and Hydrilla (a submersed weed similar to Cabomba) are shown in Figure 2. Press optimisation is an important area for engineering research.

Lightweight experimental presses, probably immediately suitable for general use in developing countries, have been designed in a current research programme.* A 9" press of this design weighs between 500-600 lbs., complete with power plant; it can be truck-, trailer-,

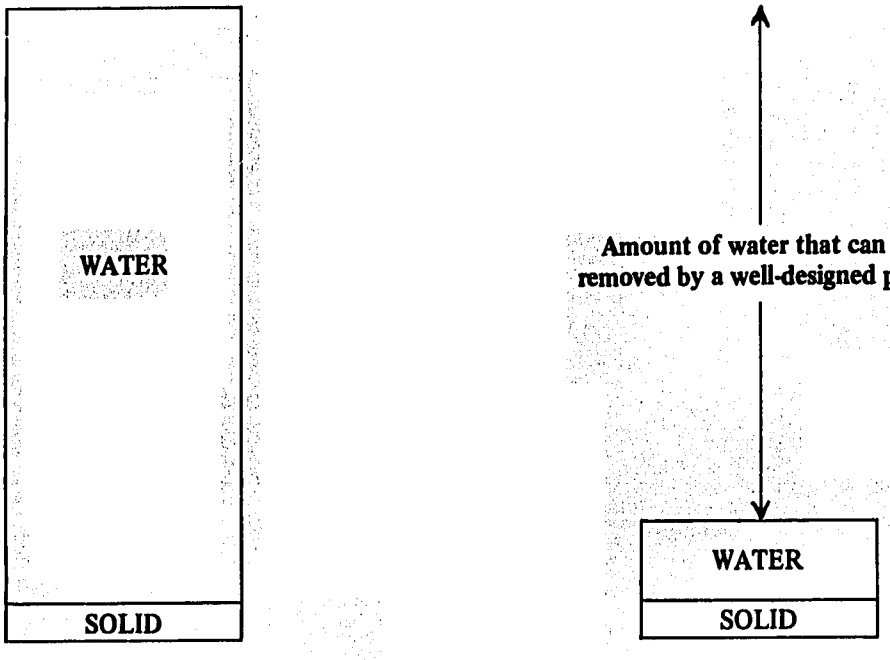

Figure 1

FRESH WATER HYACINTH (95%water)

PRESSED PRODUCT (70% water removal)

The screw press is a conventional industrial machine, commonly used to separate liquid and fibrous fractions of various types of material, e.g. oil

* One of these units, purchased by USAID, was demonstrated in Guyana during the Workshop. It is now undergoing testing to determine its potential value to Guyana. (Bagnall 1973).

or barge-carried to remote locations, and can press up to 4 tons of chopped hyacinth per hour. Twelve and sixteen-inch presses have been built using the same design and have higher capacity. The smaller sized presses are compatible with a programme of manual harvest and with the small-scale needs of a developing animal-feed industry. The design is such that most components should be available locally, and the presses can be built in developing countries.

Estimates of water hyacinth pressing-cost range from US$2.00 to US$9.31 per ton of dry matter, depending greatly on machine cost, machine use, production rate, amortisation time, and labour costs. Less than 4 hp hours is required to remove a ton of water, leading to an energy cost of US$1.06 per dry ton (Bagnall, 1973).

In macerating-pressing such as screw pressing, solids content of the juice is relatively constant at about 1.5%, so solids loss is roughly proprotional to water removal. If this juice is returned to the water it is a source of pollution. It is, however, far less than the pollution caused by weed control methods (e.g. chemical) that dump all of the vegetation into the waterway to rot. It is even less than the pollution caused by detritus from the plants if they are left to grow unmolested.

In laboratory tests, up to 75% of juice solids were recovered (as a 4% dry matter paste) by filtration, up to 80% (as a 10% dry matter cake) by centrifuging, and up to 75% (as a 4% dry matter curd) by heating the juice (Bagnall, 1973). Analysis of a composite filter and centrifuge product showed it to contain 45% crude protein. Hydrocycloning is an alternative to centrifuging for recovering nutrients, and an industrial process to use it (and add the nutrients back to the press cake) is under development (Wahl, 1972).

One can heat-treat the fresh vegetation before pressing. This causes protein de-naturation and coagulation, which traps other cellular matter and stops it from being removed as solubles in the press water.

The subject of juice recovery is one for research; positive results will improve the efficiency of mechanical dewatering of aquatic plants. Nevertheless, today's systems are operational and produce a dewatered produce with important potential for Guyana (see next Chapter).

In the U.S., mechanically dewatered aquatic weed has often been subjected to evaporative drying in conventional forage dryers to reduce moisture content, and so prevent moulding on storage. Because of forage marketing requirements in the U.S. much of the aquatic vegetation has been converted to pellets or cubes. Water hyacinth has proved more abrasive than alfalfa, and generally the aquatic plants require more pressure to make pellets. Nonetheless, many tons have been made to date.

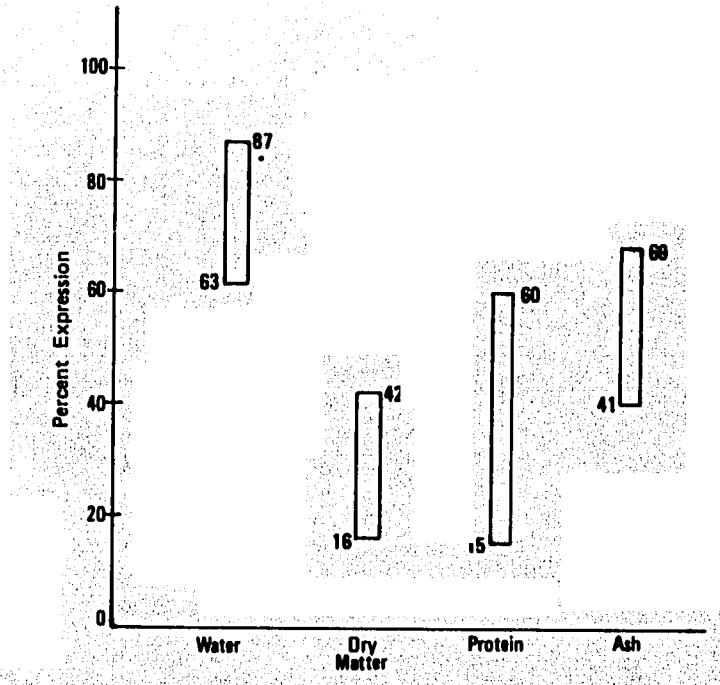

FIGURE 2 Range of press performance with samples of Water Hyacinth and Hydrilla*

* Based on experiments by N.A.S. panelist Dr. L.O. Bagnall

CHAPTER 7

DEWATERED AQUATIC WEEDS AS ANIMAL FEED

Guyana continues to have a high food import bill. Of this, a substantial portion is in livestock products, especially in frozen meat and meat products. An increase in local livestock production is needed if the aim of achieving a greater degree of self-sufficiency in food production is to be realised. Although the average calorific consumption in Guyana is high, the *per capita* consumption of protein is low, and there is need for increased consumption of animal protein products.

In some parts of the world aquatic plants are used as animal feed. In Southeast Asia, water hyacinth is a common ingredient in pig swill. The plants are grown in ponds fertilised by human and domestic animal excrement. After harvest, they are boiled with rice bran or other industrial by-product feeds, and the resulting diet is fed as liquid. This practice is widespread in Taiwan, Thailand, and Indonesia. During dry seasons in Bangladesh and West Bengal, water hyacinth is hand-harvested and fed directly to cattle, sheep, and goats; they do poorly on it, but it is the only green vegetation available.

Preservation of Aquatic Plants as Silage

Mechanically dewatered aquatic weeds are too wet to store but have a moisture content (varying from 80-88%) that is suitable for ensiling. Preserving and storing the weed press-cake as silage avoids the need to further reduce the moisture level by any other (expensive) drying methods.

In silage the weeds are preserved by organic acids produced during fermentation. When the herbage is placed in the silo, respiration of plant cells continues until the oxygen is exhausted; then naturally occurring bacteria ferment the plant components to produce lactic and other organic acids. This process takes about 20 days, and results in silage with pH below 4.0. Well-made silage is relished by ruminating animals and has a very nutritive value. Water hyacinth press residue has been shown in extensive experiments in Florida to produce a highly palatable, digestible, and nutritious silage that is readily accepted by cattle and sheep (Baldwin et al., 1973). In fact, the first large-scale commercial production of water hyacinth ensilage occurred in Florida in 1972 (Hentges et al., 1973). Silage was made in many pilot-scale silos, as well as in a full-sized tower silo. No fundamental problems were encountered in the process. The silage proved acceptable to cattle and sheep, and though nutritive levels were lower than those of terrestrial-grass silages, the digestibility of the nutrients proved satisfactory. The water hyacinth fibres proved to have exceptional water-retention properties, which were favourable for handling and transport of the press residue without seepage. These properties also allowed ensiling with a higher moisture material than normal.

A high ash content in press residue retarded development of sustained organic acid fermentation. Aquatic plants rooted in soil either should not be used for silage or their roots should be washed to remove organic matter. One should also be alert to the hazards of botulism contamination from the bottom muds.

While the ensiling process is easily mastered, success is dependent on knowing the steps in the fermentation process. The first essential requirement is to achieve and maintain oxygen-free conditions. This is accomplished by chopping the herbage into small particles and firmly packing it into the silo or stack.

The second essential requirement is to achieve a sustained fermentation that produces the correct organic acids, especially lactic and acetic acids.

Fortunately, the bacteria that produce the desired fermentation are normally present in forages. If it is determined that an appropriate flora of micro-organisms are not present in submersed aquatics, it may be necessary to add a starting culture.

Aquatic weeds are often low in fermentable carbohydrate content; consequently, materials containing these nutrients essential for bacterial action must be mixed with the plants as they are placed in the silo. Pressed aquatic weed may require the addition of absorbent materials pulp for preservation as silage. In Florida, dried citrus pulp and sugarcane molasses have been added to water hyacinth press residue as sources of carbohydrate and as molasses absorbents. In Guyana, industrial wastes and by-products of the rice, grain, and sugarcane milling industries are all potential substitutes.

In a number of countries silage treated with formic acid has proved superior to untreated silage as a feed for cattle. As a general guide, the more "difficult" crops to ensile (aquatic plants may be included in this category) benefit most from the use of acid preservatives. Formic acid, a liquid, has been applied under carefully supervised conditions at the rate of ½ gallon per ton of pressed water hyacinth. The acid inhibited undesirable bacteria and moulds, and kept the fermentation temperature down so that a nutritious "cold silage" was produced. Studies with various other organic acid preservatives (including acetic and propionic) for dewatered water hyacinth silage have all been successful too. Silages produced this way were preferred by cattle over untreated silage. Also, spoilage was reduced (Byron, 1973).

Ensiling processes may be particularly important in tropical and sub-tropical regions where a high relative humidity and frequent rains make hay-making difficult. Because silage contains considerable moisture, silos must be located adjacent to the vegetation supply and, if possible, to the market or feeding facility. Luckily, stack and tower silos can be built on most farm sites regardless of the level of water table. Another advantageous silo location may be near sewage or industrial waste lagoons, where water hyacinth crops might be grown to remove pollutants from the waste water.

Potential Toxicity of Aquatic Plants as Feeds for Livestock

No evidence of toxicity has been reported in numerous short-term feeding experiments with water hyacinth and **Hydrilla**, either dehydrated or ensiled. Live-animal performance, internal organ appearance, and carcass quality have been used as criteria in tests with sheep and cattle fed the processed aquatic plants at a maximum tolerance level in balanced diets. In studies at Florida (Hentges et al., 1972) one group of six yearling cattle were offered dried water hyacinth at a maximum tolerance level in their diets for nine months without apparent toxic effects or digestive disturbances. No liver abscesses, enteritis, or other abnormalities were found in the organs of the cattle, and all of the carcasses were graded as U.S. Choice.

Shirley and Easley (1972) have reported data on the concentration of three potential toxicants in water hyacinth and **Hydrilla**. The highest nitrate level found in water hyacinth was 0.3%, and it typically ranged from 0.05 to 0.1% throughout a year of monthly samplings. They considered such levels safe for cattle in the light of published literature. Tannins were found in the dewatered plants too, and they may interfere with protein digestion. However, here again the concentrations were not high enough to be of major importance. A relatively high oxalate content was also found, and has importance because oxalates in feed combine with calcium, withholding its use from animals. Oxalates are generally not hazardous to ruminants or nonruminants when liberal amounts of calcium are included in their diets, and water hyacinth contains considerable amounts of calcium which should make up for any losses caused by oxalates. Steers fed diets containing water hyacinth and **Hydrilla** products tolerated the three potential toxicants without apparent effect upon performance.

Traces of pesticides have been found in most samples of Florida's aquatic plants; consequently, the plants are tested before being processed into animal feed. Such residues could cause a problem only if the plants had been chemically treated immediately prior to harvesting.

In canals and waterways which are excessively polluted with animal waste, a problem arises from pathogenic bacteria. Therefore, aquatic plants harvested from such waters should be screened for harmful pathogenic bacteria before use in livestock diets.

Utilisation of Artifically Dried Aquatic Plants in Livestock Diets

The only aquatic plant press-cakes which have been artifically dried and fed to livestock are water hyacinth, **Hydrilla** (Salveson et al., 1973) and water milfoil (Bruhn et al., 1971). In these studies the processing machinery may have denatured much of the protein and removed most of the soluble nutrients in the press juice. However, for fibre content alone

dehydrated water hyacinth has a replacement value at least equal to the competitive products, cottonseed hulls and sugarcane bagasse. The minimum content of these ingredients in feeds would range from 8% in beef cattle feedlot diets to 20% in lactating dairy cow diets.

In other studies (Salveson et al., 1971; Stephens, 1972) the digestibility of organic and inorganic matter in diets containing two dried aquatic plants and one land forage was determined for yearling beef steers in metabolism crates. The test materials were water hyacinth and **Hydrilla** press residues, and immature coastal bermuda-grass **(Cynodon dactylon)** hay. All were dried and pelleted and used as 33% of the dry organic matter in each diet.

The cattle's voluntary intake of dry and organic matter for the coastal bermuda-grass diet was higher than for the **Hydrilla** diet, but not significantly different from the water hyacinth diet. There was no significant difference in water intake, although steers consuming the **Hydrilla** diet, which contained more ash, drank slightly more water. The mean voluntary intakes of dry matter per day for the coastal bermuda-grass, **Hydrilla** and water hyacinth diets were 24, 17, and 21 grams per kg. body weight, respectively. These intakes were adequate for maintenance of body weight and positive nitrogen balance with all test diets. Digestion coefficients for nutrients in the aquatic plant diet were lower than for the land forage, but this might be explained by harsh conditions during processing.

Cattle fed the bermuda-grass diet retained more phosphorous and less calcium, magnesium, and potassium than those fed the **Hydrilla** diet, but retained more calcium and less sodium than those fed the water hyacinth diet. Those fed the **Hydrilla** diet retained more calcium and magnesium, and less phosphorous and manganese, than the animals fed the water hyacinth diet. There were no significant differences in the retention of sulphur, iron, copper, and zinc by the three groups. There were no significant differences between the apparent absorption values of sand-silica in the diets.

The U.S. National Research Council* inorganic-element requirements for growing beef cattle were supplied in the diets containing water hyacinth and coastal bermuda-grass diets except for copper, zinc, and potassium, and in the diet containing **Hydrilla** except for phosphorous and copper. Comparative retention of minerals by the steers indicated that inorganic elements are essentially as available in the aquatic plant diets as in the land forage diet; therefore, the ash of aquatic plant feedstuffs may contribute significantly to the dietary requirements of ruminants.

Other Livestock

Poultry are kept throughout Guyana though there is still considerable room for expansion in a growing domestic market, especially in egg production, for the country is by no means self-sufficient.

Little is known of the value of aquatic plants in poultry rations though, as already noted, valuable xanthophyll and carotenes, the yellow pigments in egg yolk and broiler skin, are very high in some submersed plants. The pigments in water milfoil and other submersed weeds have been reported (Couch et al., 1964) to be absorbed and metabolised by poultry. The similarity of **Cabomba** to water milfoil and other high xanthophyll/carotene aquatic plants makes it a leading candidate to study for use in poultry feed in Guyana.

Few pig farms exist in Guyana. Pigs are usually reared in conjunction with some other farming occupation. They are found mainly in the Pomeroon, but are also scattered throughout the coastal belt. The pig industry also offers considerable room for expansion.

The utilisation of dried water hyacinth and **Hydrilla** in swine diets was studied by Combs (1972) in Florida. While the nutrients were utilised at a low level of intake, the bulky nature of the test products coupled with inadequate processing procedures led to inconclusive results.

* Nutrient Requirements of Beef Cattle, National Academy of Sciences, Washington, D.C., U.S.A.

CHAPTER 8

AQUATIC WEED AS SOIL ADDITIVES

Except for the 'frontland clays' of the coastal plain, Guyana's soils are generally not amenable to intensive agricultural production without considerable soil preparation. The coastal soils are suitable for agriculture only after draining, though even then they are generally intractable clays or silty-clays and can be much improved by mulches.

The 'Clay and Sand' belt which parallels the Coastal Belt derives its name from its characteristic soil formation. Both sand and clay soils require conditioning to become productive. Sand needs organic matter and nutrients; clay needs texturing to make it friable. Research has shown that pressed aquatic weeds (or compost made with them) can be used as manure, and provides a very satisfactory source of organic matter, nutrients, and soil texturing.

In Florida pressed water hyacinth is being marketed on a small scale as a peat moss substitute in which to grow seedlings and mushrooms (Leach 1972). In Wisconsin (Koegel et al., 1972) it has been demonstrated that large quantities of aquatic weeds press-cake can be disposed of, to advantage, if spread on lawns or grassland, using conventional manure spreaders. It is reported that the fertiliser value is slightly better than that of cow manure.

The nitrogen and potash 'fertiliser units' are quite high (see also Chapter 3), and in Guyana it has been estimated (Bates 1973) that the yields recoverable from waterways are:

	Water Hyacinth	Water Lettuce
Nitrogen	351 lb/acre/annum	169 lb/acre/annum
Potassium	729 lb/acre/annum	361 lb/acre/annum
Phosphorous (as P_2O_5)	116 lb/acre/annum	43 lb/acre/annum

These figures were based on plant growth of 100 and 60 tons of water hyacinth and water lettuce per acre per annum respectively and, as previously noted, may in practice prove to be low estimates.

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