ICLARM STUDIES AND REVIEWS 5

# Food Potential of Aquatic Macrophytes

Peter Edwards

INTERNATIONAL CENTER FOR LIVING AQUATIC RESOURCES MANAGEMENT

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PETER EDWARDS

Associate Professor of Aquaculture
Division of Agricultural and Food Engineering
Asian Institute of Technology
P.O. Box 2754, Bangkok
Thailand

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INTERNATIONAL CENTER FOR LIVING AQUATIC RESOURCES MANAGEMENT
MANILA, PHILIPPINES

# Food Potential of Aquatic Macrophytes

By PETER EDWARDS

1980

Published by the International Center for Living Aquatic Resources Management
MCC P.O. Box 1501, Makati, Metro Manila, Philippines

Printed in the Philippines

Edwards, P. 1980. Food potential of aquatic macrophytes.
ICLARM Studies and Reviews 5, 51 p. International Center for
Living Aquatic Resources Management, Manila, Philippines.

ISSN 0115-4389

Cover: Harvesting the duckweed, *Spirodela*, for feed
from a eutrophic borrow pit, Thailand

# PREFACE

The present paper is an attempt to review critically the various aspects in which aquatic macrophytes may be used in food production. The term "weed", to refer to aquatic macrophytes, has been purposefully avoided as far as possible, since, as pointed out by certain authors, involving them in the food production process may be a far more effective control method than their mere destruction. Furthermore, several species have considerable potential in their own right and warrant detailed study. Indeed, considerable benefit would accrue to the field of aquaculture in general, if botanical aspects of the subject were given due attention.

The initial version of this paper resulted from a request to submit a manuscript to the ICLARM-SEARCA Conference on Integrated Agriculture-Aquaculture Farming Systems, held in Manila, Philippines, 6-9 August 1979. I was requested to prepare a review paper on nutrient reclamation from manure-loaded ponds, with an emphasis on the production of crops of aquatic macrophytes for animal feed and/or human consumption. I soon found the initial title too restrictive, mainly because of sparse data in the literature on this topic, but also because of difficulty in delimiting the original topic.

It soon became apparent that aquatic macrophytes may be involved in a plethora of complex interactions in food production and difficulty was experienced in organizing the available data in a readily digestible form. The intention has been to indicate the role of aquatic macrophytes in food production, and I hope that the research recommendations made in the summary of the text may be of use in focusing future studies on these underexploited plants.

PETER EDWARDS
March 1980
Bangkok

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DR. PETER EDWARDS
*Associate Professor of Aquaculture*
*Division of Agricultural and Food Engineering*
*Asian Institute of Technology*
*P. O. Box 2754, Bangkok, Thailand*

## ABSTRACT

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A review is presented of the pathways in which aquatic macrophytes may be involved in the food production process, directly as human food, as livestock fodder, as fertilizer (mulch and manure, ash, green manure, compost, biogas slurry), and as food for aquatic herbivores, such as fish, turtles, rodents and manatees. An attempt is made to identify the strategies which may have the greatest potential at present. The following research areas are suggested as worthy of attention: protein content and yield of *Ipomoea aquatica* and *Neptunia oleracea,* two vegetables which grow year round in the tropics and can be propagated from cuttings; protein content and yield of various types of duckweed in the tropics as a function of different concentrations of various organic wastes; *Azolla* and filamentous blue green algae as biofertilizers; composting aquatic macrophytes and the use of the compost as an organic fertilizer in fish ponds; aquatic macrophytes in biogas production and the use of the slurry as an organic fertilizer in fish ponds, and the feasibility of stocking herbivorous fish in irrigation systems with large aquatic macrophyte populations.

## INTRODUCTION

The prolific growth of several species of aquatic macrophytes in certain water bodies leads to a multitude of problems. Because of the adverse effects of such dense vegetation, there is a voluminous literature on the control of aquatic macrophytes, with emphasis on their destruction (Little 1968; Boyd 1972; Ruskin and Shipley 1976). There is also the paradox of food shortages coexisting with large expanses of aquatic vegetation in many developing countries, where the utilization of these plants as food would convert a weed problem into a valuable crop (Boyd 1974). In one sense, they provide a highly productive crop that requires no tillage, seed, or fertilization (Ruskin and Shipley 1976). This dilemma is reflected in the titles of two papers on aquatic macrophytes, "Water hyacinth, curse or crop?" (Pirie 1960) and, "Aquatic weeds–eradicate or cultivate?" (Bates and Hentges 1976).

Pleas have been made to direct research towards finding uses for aquatic macrophytes instead of concentrating efforts on eradication (Pirie 1960). According to

Little (1968), what is needed is, "a radical change of thinking since once a plant is called a weed it becomes accepted as being useless. It is better to define a weed as a plant whose usefulness has yet to be discerned. Efforts to get rid of it may be more energetic if some return is obtained from the labour involved." It is well to remember that not all aquatic macrophytes cause problems and that rice, the most important, single crop species in the world, is an aquatic macrophyte.

An attempt is made in this review to identify ways in which aquatic macrophytes may be used in the food production process. A schema is presented which outlines strategies in which aquatic macrophytes are presently involved, or could become involved, in food production (Fig. 1). Those strategies which may have the greatest value or potential are identified.

However, because a certain strategy is recommended as worthy of attention, it does not necessarily mean that it should be implemented in a given locality, but rather that it should be considered against all other alternative uses of the aquatic macrophyte and/or utilization of the available space and energy inputs available. The final choice is likely to be influenced by a variety of factors including the physical environment, the climate, the degree of development of the area, marketing facilities, and local customs.

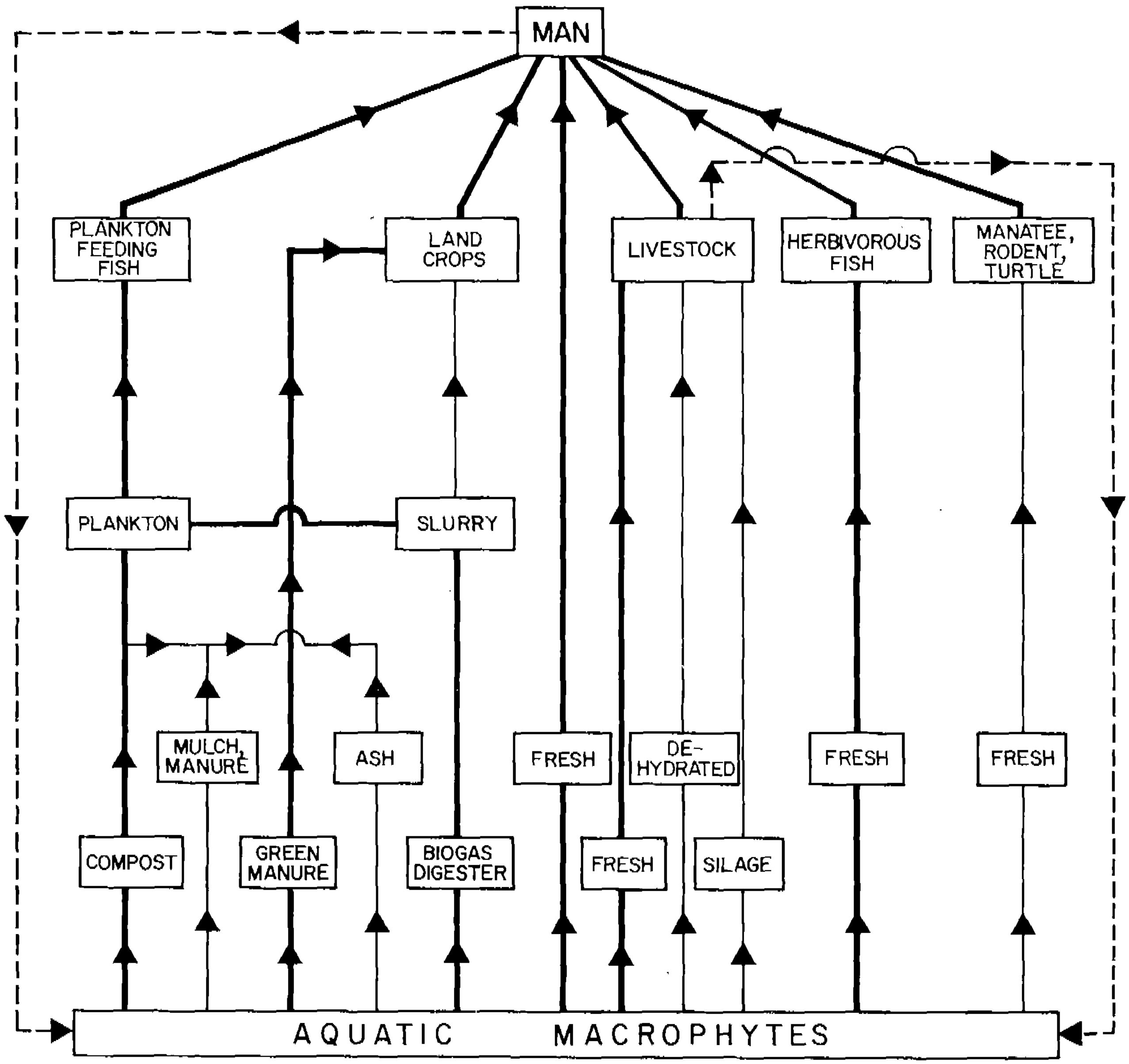


Figure 1. A scheme of the major pathways involving aquatic macrophytes in food production. Pathways which may have the greatest potential at present are in a heavier solid line. The dashed line indicates that the recycling of livestock and human wastes could play an important role in food production.

## DEFINITION OF AQUATIC MACROPHYTE

There is no strict definition of an aquatic macrophyte since certain plants thrive in the transition zone from aquatic to terrestrial environments, and in environments that may be flooded at certain times of the year. Aquatic plants are considered as those which grow in a continuous supply of water or are at least present in soils which are covered with water during a major part of the growing season (Penfound 1956; Cook et al. 1974; Mitchell 1974). The term macrophyte distinguishes larger plants from the phytoplankton. Filamentous algae are considered as macrophytes since they often form floating masses which can be easily harvested, although many have microscopic, individual filaments. Marine and brackish water plants are excluded from this review.

Aquatic macrophytes may be divided into several life forms, a somewhat arbitrary separation since there are plants which are intermediate, or which may change their life form depending on their stage of growth or on the depth of water (Penfound 1956; Mitchell 1969, 1974; Cook et al. 1974). The major life forms are: 1. Emergent species, which are rooted in shallow water with vegetative parts which emerge above the water surface, e.g., *Typha* and *Phragmites.* 2. Submersed species which are usually rooted with vegetative parts which are predominantly submerged, e.g., *Potamogeton* and *Myriophyllum.* 3. Floating species with the roots, if present, hanging in the water, e.g., *Eichhornia* and *Lemna.*

There is frequently a pronounced zonation of life forms, with emergent species growing in the shallow water and the submersed species growing in deeper water in which light still penetrates to the bottom. Floating species are not dependent on soil or water depth (Penfound 1956; Mitchell 1974).

## PROBLEMS CAUSED BY AQUATIC MACROPHYTES

A detailed discussion of the problems caused by certain aquatic macrophytes in outside the scope of this review, but some of the major problems are listed below to put into perspective the relevance of developing methods for their utilization and thus their control. These include: water loss by evapo-transpiration; clogging of irrigation pumps and hydroelectric schemes; obstruction of water flow; reduction of fish yields and prevention of fishing activities; interference with navigation; public health problems; retardation of growth of cultivated aquatic macrophyte crops, e.g., rice and water chestnut, *Trapa bispinosa,* and conversion of shallow inland waters to swamps (Little 1969; Cook and Gut 1971; Mitchell 1974; Biotrop 1976; Chaudhuri et al. 1976; Kotalawala 1976; Sankaran 1976; Thomas 1976).

The problem of aquatic macrophyte infestation is global but is particularly severe in the tropics and subtropics where elevated temperatures favour year round or long growing seasons, respectively (Holm et al. 1969). The annual world cost of attempts to control aquatic macrophytes is said to be nearly US$2,000 million (Pirie 1978).

The most serious problems are caused by the water hyacinth, *Eichhornia crassipes* (Fig. 2), which is now more or less ubiquitous in warm waters (Robson 1976) but which, it seems, only started its world-wide journey as an ornamental plant when first introduced into the USA, probably at the 1884 Cotton Centennial Exposition in New Orleans (Penfound and Earle 1948). In the tropical and subtropical S.E. U.S.A., there is a serious water hyacinth problem; in Florida alone more than 40,000 ha are covered by the plant despite a continuous control program costing US$10-15 million annually (Frank 1976). Subsistence level farmers in the wet lowlands of Bangladesh annually face disaster when rafts of water hyacinth weighing up to 300 t/ha are carried over their rice paddies by floodwaters. The plants remain on the germinating rice and kill it as the floods recede (Ruskin and Shipley 1976).

Another problematical aquatic macrophyte is the fern *Salvinia molesta,* on Lake Kariba, Africa, the largest man made lake in the world (Schelpe 1961; Boughey 1963; Little 1966; Mitchell 1974); there was a steady increase in the area of the lake colonized by the fern following closure of the dam in 1959 until 1962, when 1,000 $km^2$ or 2.5% of the lake's surface was covered; since 1964 the area covered has fluctuated between 600 and 850 $km^2$ and is limited mainly by wave action which has increased as the lake has reached full size (Mitchell 1969). The same species is a serious threat to rice cultivation throughout western Sri Lanka (Williams 1956) and covers about 12,000 ha of swamp and paddy fields (Dassanayake 1976).

*Eichhornia crassipes* came orginally from South America where it causes few problems since it is kept in check by periodic flooding and changes in water levels; the plants are flushed out as a given water body enlarges due to seasonal flooding and as the floods subside the aquatic plants are left stranded on dry land above the receding water level (Mitchell 1976). The absence of natural enemies in their new environments has often been implicated as a causal factor in the rampant growth of aquatic macrophytes (Michewicz et al. 1972a) and is the basis for a search for such organisms for their control. There is, however, little evidence that the various insects which use them as food, exercise marked control (Mitchell 1976). The absence of periodic flooding in artificial lakes and irrigation schemes may be the major contribut-

Figure 2. A dense cover of water hyacinth, *Eichhornia crassipes,* Thailand.

ing factor to the development of a macrophyte problem, and this may be exacerbated by eutrophication from human, animal and agroindustrial wastes, and agricultural runoff. As new lakes and irrigation schemes are developed the newly submerged soil and vegetation may also provide a rich source of nutrients which favor aquatic plant growth (Little 1968).

PRODUCTIVITY OF AQUATIC MACROPHYTES

It is now known that freshwater ecosystems are some of the most productive on earth (Likens 1973) and it appears that certain types of aquatic macrophytes, e.g., rooted emergent species and floating species, may be the most productive vegetation of all (Penfound 1956). Westlake (1966) presented the following typical values for the net production of different types of aquatic vegetation from fertile sites: lake phytoplankton 1 to 9, submersed macrophytes 4 to 20 and emergent macrophytes 30 to 85 t of dry organic matter/ha/yr. At that time, the highest net productivity recorded was for sugar cane, 94 t dry matter/ha/yr (Westlake 1963).

Phytoplankton are outside the scope of this review but it should be pointed out that very high productivities, exceeding 100 t dry matter/ha/yr, have been obtained from high rate sewage stabilization ponds (McGarry and Tongkasame 1971). The productivity of subersed macrophytes is usually low because the water reflects and absorbs some of the incident light, colored substances in the water absorb light, and the diffusion of carbon dioxide in solution is slow compared to its diffusion in air (Westlake 1963). The presence of phytoplankton in the water column also reduces the light available for submersed plants and in eutrophic waters may be dense enough to cause the elimination of aquatic macrophytes.

It is thought that emergent macrophytes are particularly productive since they make the best use of all three possible states with their roots in sediments beneath water and with the photosynthetic parts of the plant in the air (Westlake 1963). The reducing mud around the roots may be a good source of soluble nutrients which can diffuse to the roots via the pore water in the sediments; light and carbon dioxide are more readily available in air than in water. Thus, they make the best of both aquatic and terrestrial environments. It seems remarkable that natural aquatic macrophyte vegetation can have a productivity equal to or exceeding that of crop species which have been selected for high yield and are cultivated under near optimal conditions with fertilization, irrigation, pest and weed control (Westlake 1963).

Westlake (1963) predicted that *Eichhornia crassipes* might be an exceptionally productive plant since it is a warm water species with submerged roots and aerial leaves like emergent macrophytes. When he wrote his review there were no reliable productivity data available. Using the data of Penfound and Earle (1948) he calculated an annual production of 15 to 44 t/ha for water hyacinth but he predicted that 200 t/ha may be possible if the plant were cultivated so that young plants always predominated and the water surface were always covered, yet without exceeding the density which would decrease efficiency by self-shading. Yount and Crossman (1970) reported an average productivity of water hyacinth in artificial, fertilized ponds of 20.7 $g/m^2/d$ which can be extrapolated to 75.6 t/ha/yr; however, measurements of more than 40 $g/m^2/d$, which can be extrapolated to 146 t dry matter/ha/yr, were not uncommon, and in one pond they obtained a net productivity of greater than 54 $g/m^2/d$, which can be extrapolated to 197.1 t dry matter/ha/yr. Boyd (1976) also studied the productivity of water hyacinth in fertilized ponds, but reported a lower average growth rate of 194 kg/ha/d over a 5 mo period, which may be extrapolated to 70.8 t/ha/yr. Wolverton et al. (1976) reported a net productivity of 600 kg dry matter/ha/d under favorable conditions using sewage effluent, which can be extrapolated to 219 t dry matter/ha/yr with a year round growing season. Wolverton and McDonald (1976) considered that annual production rates of 212 t dry matter/ha are possible based on their studies. They also reported, however, that water hyacinth fed on sewage nutrients can yield 0.9 to 1.8 t dry plant material/d, which can be extrapolated to 329 to 657 t/ha/yr. It is probably not possible to obtain the higher calculated annual productivities on a large scale, since it would be difficult to maintain the most rapid growth rates obtained on small experimental scale throughout the year, even in the tropics, but it does seem that water hyacinth annual production in the order of 200 t/ha/yr may be attainable in the tropics in eutrophic water.

A major reason for the problems caused by certain species of aquatic macrophytes is their ability for rapid vegetative growth, which often leads to explosive growth of the population (Mitchell 1976). *Salvinia molesta* mats on Lake Kariba have a mean doubling time of 11.6 d in the middle of the mat and 8.6 d at the edge of the mat (Mitchell 1974). Evans (1963) reported that 2 plants of *Eichhornia crassipes* gave rise to 1,200 plants by vegetative reproduction in 130 d on the Congo River. Penfound and Earle (1948) obtained a doubling rate of 11 to 18 d, depending on the weather, for *Eichhornia crassipes;* they estimated that 10 plants, with unlimited space and good growing conditions, would produce 655,360 plants in 8 mo, assuming an average doubling rate of 14 d. Even faster growth rates are possible with optimal nutrient conditions. Mitchell (1974) obtained doubling times for *Salvinia molesta* of 4.6 to 8.9 d in culture solutions in the laboratory, compared to 8.6 d on Lake Kariba. Bagnall et al. (1974b) reported a doubling time of 6.2 d for *Eichhornia crassipes* grown on an stabilization pond receiving secondary treated effluent, which is about double the rate reported by Penfound and Earle (1948) under natural conditions for the same species.

## COMPOSITION OF AQUATIC MACROPHYTES

Aquatic macrophytes have a high water content in general, which is usually a major deterrent to their harvest and utilization. According to Boyd (1968a) the water content of 12 submersed species varied from 84.2 to 94.8%, and 19 emergent species from 76.1 to 89.7%. The water content of floating macrophytes varied from 89.3 to 96.1% (Little and Henson 1967; Lawson et al. 1974). The differences among the various life forms can be correlated to some extent with the amount of fiber present in the plant: water supports the weight of submersed plants so they do not develop tough fibrous stems for support like emergent species, whereas floating forms have less fiber than most emergent plants but more than submersed species (Ruskin and Shipley 1976).

Since pasture grass is about 80% water, if an average value of 92% water is used for aquatic macrophytes, then 2.5 times as much freshwater plant is required to obtain the same amount of dry plant matter as in pasture grass (Little and Henson 1967).

There is considerable interspecific variation in the proximate composition of dried aquatic macrophytes. Comparisons have been made with alfalfa, a conventional terrestrial forage, and while many aquatic macrophytes are inferior to alfalfa as livestock feed, several are as suitable or better (Boyd 1974).

Boyd (1968b) obtained crude protein values of 8.5 to 22.8% dry weight for 12 sumbersed plants, 9.3 to 23.7% dry weight for 19 emergent plants and 16.7 to 31.3% for 8 non-planktonic algae. Linn et al. (1975a) obtained a range of crude protein values of 5.8 to 21.8% for 21 species of dried aquatic macrophytes, compared to 16.9% for alfalfa hay. Higher crude protein values have been reported, e.g., duckweed as high as 42.6% (Myers 1977) and the blue green alga *Spirulina,* 60 to 70% (Ruskin 1975).

There are considerable intraspecific variations in crude protein content due to both seasonality and environment. The crude protein content of *Typha latifolia* decreased from 10.5% in April to 3.2% in July (Boyd 1970a) and that of *Justicia americana* from 22.8% in May to 12.5% in September (Boyd 1974). The crude protein content of water hyacinth ranged from a low of 4.7% in summer to a high of 9.2% in spring (Taylor et al. 1971). If the crude protein content is usually higher when the plant is younger, the maximum standing crop of protein will occur earlier than the maximum standing crop of dry matter and the harvesting strategy will need to be adjusted accordingly (Boyd 1968b), 1970a, 1974). Boyd (1969) determined the crude protein content of water hyacinth, water lettuce, and *Hydrilla* from a wide variety of environmental conditions, and while there were only slight differences in the mean crude protein for the three species, there were wide ranges for each species. The crude protein content of *Typha latifolia* from different sites varied from 4.0 to 11.9% (Boyd 1970a); that of water hyacinth grown on a stabilization pond was 14.8% compared to 11.3% in samples from a lake (Bagnall et al. 1974b). There is evidence that the crude protein content increases as the nutrient content of the water in which the plant is grown increases. According to Wolverton and McDonald (1979a), the crude protein content of water hyacinth leaves grown on waste water lagoons averaged 32.9% dry weight, which is comparable to the protein content of soybean and cotton seed meal. This value is more than three times the maximum crude protein content of water hyacinth reported by Taylor et al. (1971). Similar variations are reported for duckweed (*vide* section on Livestock Fodder).

Although the total protein content of aquatic macrophytes differs greatly, the amino acid composition of the protein from many species is relatively constant, nutritionally balanced, and similar to many forage crops (Taylor and Robbins 1968; Boyd 1969, 1970a; Taylor et al. 1971).

The concentrations of inorganic elements in most species of aquatic macrophytes fall within the range of values for crop plants (Boyd 1974). However, there may be considerable interspecific differences in certain minerals (Boyd 1970c; Adams et al. 1973; Easley and Shirley 1974; Linn et al. 1975a) and also considerable intraspecific differences in plants harvested at different seasons and from different localities (Fish and Will 1966; Boyd and Vickers 1971; Adams et al. 1973). The low palatability of aquatic macrophytes to livestock has been attributed to a high mineral content (*vide* section on Livestock Fodder).

# Aquatic Macrophytes as Human Food

Throughout history man has used some 3,000 plants for food and at least 150 have been commercially cultivated. However, over the centuries there has been a tendency to concentrate on fewer and fewer plants so that today most of the world's people are fed by about 20 crop species (Ruskin 1975). The only aquatic plant that is a major agronomic species is the emergent macrophyte rice, *Oryza sativa,* but it is the most important single crop species in the world and forms a staple diet for more than 50% of the world's population (Boyd 1974; Cook et al. 1974). A small number of other aquatic plants are used for human food but for the majority there are few data available. A few of these are farmed but they are produced by traditional methods, and only rice has been the subject of concentrated research. The cultivation of aquatic plants is a grossly neglected area of aquaculture (Ruskin and Shipley 1976) and it is timely to consider such neglected or little known species of crops to determine their potential role in increasing human food supply. Aquatic macrophytes can be grown on waterlogged or swampy land which is at present underutilized since it is not suitable for either conventional agricultural crops or aquaculture (Ruskin and Shipley 1976).

A novel use of aquatic macrophytes is for the construction of floating vegetable gardens. Bottom mud is scooped up and placed onto floating mats of aquatic vegetation which are anchored by poles, and crops are grown in the nutrient rich mud and abundant water supply. The Aztecs used such gardens in Mexico before the arrival of the Europeans and today they are used in Bangladesh, Burma and Kashmir (Ruskin and Shipley 1976). They may have potential for land-poor farmers in regions where there are large areas of protected water surface.

An account is presented below of those species of aquatic macrophytes that are used for human food. They provide three types of food: foliage for use as green vegetables, grain or seeds, and swollen fleshy roots that consist mainly of starch. The classification used follows Cook et al. (1974).

## ALGAE

*Spirulina,* a blue green alga that is 60 to 70% protein and rich in vitamins, particularly $B_{12}$, appears to be a promising plant. *S. platensis* is native to Lake Chad in Africa and is harvested from its waters for human consumption. Although the individual filaments are microscopic, it can be harvested by simple filtration when growing in abundance. The villagers by Lake Chad harvest the alga by pouring the water through a muslin bag. The alga is dried in the sun and cut into blocks which are cooked and eaten as a green vegetable (Ruskin 1975). When the Spanish conquistadores arrived in Mexico in the 16th century, they found the Aztecs using another species, *S. maxima,* as their main protein source. Today in Mexico, at Texcoco near Mexico City, there is a pilot plant to process about 1 t of dry *Spirulina* per day grown in mass culture. The alga is sold as a high protein, high carotene additive for chick feed but it can be added to cereals and other food products at up to 10% by volume without altering their flavour (Ruskin 1975). However, growing *Spirulina* in artificial media requires technical sophistication and there are still problems, e.g., the need to maintain a high pH by the addition of bicarbonate. *Spirulina* cultivation may certainly have a place in developing countries but it probably could not become widespread.

*Nostochopsis* sp., another blue green alga found attached to rocks in streams or at waterfalls, is eaten in western and northern Thailand. It is used as an ingredient in hot and sour fish soup or is boiled with syrup and eaten as a dessert (Lewmanomont 1978).

*Spirogyra* spp., green algae that occur in still water or slow moving streams, are eaten fresh as a vegetable or used as an ingredient in soups, particularly in northeastern Thailand (Lewmanomont 1978).

There is a report of a freshwater red alga, *Lemanea mamillosa,* that is eaten as a delicacy in Assam, India. It is sold in dry form on the market at Manipur and is eaten by the local people after frying. Since it only grows during the cold season in swiftly flowing rivers attached to boulders (Khan 1973), it has little potential for widespread use as food.

## FERNS

According to Ruskin and Shipley (1976), *Ceratopteris thalictroides* is collected wild and the fiddleheads (new fronds just uncoiling) are eaten raw or cooked. The entire plant except the root is also cooked as a green vegetable. Suwatabandhu (1950) reported that it is eaten as a green vegetable by farmers in Thailand and Biotrop (1976) also reported that the young leaves are used as a vegetable. According to Cook et al. (1974), it is cultivated in Japan as a spring vegetable.

The leaves of a second fern *Marsilea crenata* are used as a vegetable (Biotrop 1976) as are the leaves of *M. quadrifolia* in Thailand (Suwatabandhu 1950).

## HIGHER PLANTS

### Family Alismataceae

*Sagittaria* spp., arrowhead, are emergent aquatic macrophytes with eight or more underground stems, each with a corm on the end. They are boiled and used like a potato, and are a constituent in several Japanese and Chinese meat dishes. *S. trifolia (S. sinensis)* grows wild or semicultivated in swamps throughout tropical and subtropical Asia (Ruskin and Shipley 1976), although it is cultivated widely in China and Hong Kong (Herklots 1972). *S. sagittifolia* and other species are reported to be cultivated by the Chinese in many parts of the world (Cook et al. 1974). The protein content of *S. trifolia* may be 5 to 7%, which is more than twice the average value of other root crops. It is reported to be a serious and widespread weed in many countries, but since it grows quickly and requires no special care, it probably could be developed into a more widespread crop. There are no yield data but it can be harvested after 6 to 7 mo (Ruskin and Shipley 1976).

### Family Apiaceae or Umbelliferae

*Sium sisarum* is an emergent, aquatic macrophyte cultivated for its edible roots (Cook et al. 1974).

### Family Aponogetonaceae

Tubers of several species of *Aponogeton* are eaten by humans. Some species are submersed, some have floating leaves and some are emergent (Cook et al. 1974; Biotrop 1976).

### Family Araceae

*Colocasia esculenta,* taro, is an emergent, aquatic macrophyte with a starch filled rhizome that is often eaten (Cook et al. 1974). Underground there is usually one central corm and 6 to 20 spherical cormels around it, all of which are edible. It is intensively cutltivated in only a few countries, e.g., Egypt, Philippines, Hawaii and certain other Pacific and Caribbean islands, but it has world wide tropical potential. Some types grow in waterlogged and swampy soils and some cultivars are highly salt tolerant and can grow in coastal and inland saline areas. The tuberous roots are low in protein and rich in starch and compare favorably with cassava, yams, sweet potato, irish potato and rice. They are a good source of Ca, P, and vitamins A and B. They have a nutty flavor and can be boiled, baked, roasted or fried in oil. A flour similar to potato flour with a nutty flavour can be made for soups, biscuits, bread, beverages, puddings and chips. The leaves and petioles, which are rich in protein, Ca, P, Fe, K and vitamins A, B and C, can be cooked and eaten like spinach. Taro can be grown in paddy culture like rice and grows rapidly if fertilizer and water levels are maintained. The corms mature 6 to 18 months after planting. The gross income/ha in Hawaii with an average yield of 22,400 kg/ha is almost US$4,000 (Ruskin 1975; Ruskin and Shipley 1976).

*Cyrtosperma chamissonis (C. edule),* swamp taro, is another root crop that shows promise. It is a hardy plant that grows in fresh or brackish water swamps unsuitable for most crops and is one of the few crops that can be grown on coral atolls. It grows best in slowly moving water less than 1 m deep. It is grown mostly in the South Pacific and in some parts of Indonesia and the Philippines. In the Solomon Islands it is grown in coastal marshes. The corms, which can reach a weight of 100-180 kg, are rich in carbohydrate but low in protein (0.7 to 1.4%). They are cooked as a vegetable or made into flour. Some cultivars may mature in 1 to 2 years and others need 2 to 3 years; maximum yields of about 10 t/ha may need 5 to 6 yr, although it requires little care (Ruskin and Shipley 1976).

*Pistia statiotes,* water lettuce, is a floating plant that is reported to be used as a vegetable in India (Varshney and Singh 1976).

### Family Brassicaceae or Cruciferae

*Rorippa nasturtium-aquaticum (Nasturtium officinale),* water cress, an emergent plant, is a native of Europe and N. Asia, but is widely cultivated in temperate and subtropical areas and at cool altitudes in the tropics (Ruskin and Shipley 1976; Cook et al. 1974). It was introduced into Malaysia by the Europeans and has been in Java for over 100 years (Burkill 1935). According to Ruskin and Shipley (1976), it needs cool, flowing water for growth but in Hong Kong it is grown in the cooler months in the same fields that are used to raise *Ipomoea aquatica* in summer (Edie and Ho 1969). It is a rich source of Fe, $I_2$ and vitamins A, B and C (Ruskin and Shipley 1976). It is used as a fresh salad herb or cooked as a green vegetable (Burkill 1935; Cook et al. 1974; Ruskin and Shipley 1976; Biotrop 1976), but if the water is polluted it can become contaminated with amoebae and is dangerous to eat raw (Ruskin and Shipley 1976). A second species, *Nasturtium heterophyllum,* is used as a vegetable with curry in Singapore and probably Malaysia, and is used in Java for salads, raw or steamed, and soups (Burkill 1935).

Family Convolvulaceae

*Ipomoea aquatica (I. repens),* water spinach, is a floating plant that roots in marshy soil (Fig. 3). It is native to India, S.E. Asia, and S. China and is commonly eaten as a vegetable (Burkill 1935; Cook et al. 1974; Edie and Ho 1969; Ruskin and Shipley 1976; Biotrop 1976; Djajadiredja and Jangkaru 1978). The fresh young leaves and stems are boiled or fried in oil and it is sometimes used for pickles (Ruskin and Shipley 1976). Its crude protein content varies from 18.8 to 34.3% on a dry weight basis (Dirven 1965; Göhl 1975). Most of the data on this crop come from Hong Kong where it is grown on a garden scale on farms averaging only 0.08 to 0.32 ha, most of which were previously rice paddies. Despite the small sized farms, the annual Hong Kong production is 3 to 5 million kg and it supplies 15% of the local vegetables during its peak months when most other leafy crops do not grow well. The plant grows well only at a temperature greater than 25°C and therefore grows only from late March to October in Hong Kong. The seedlings are normally raised on a dry portion of the field, since germination and initial growth are poor under water. Six wk after sowing, the seedlings are transplanted into flooded fields. There is a heavy application of fertilizer, particularly nightsoil. A typical crop might receive about 3,100 kg nightsoil/ha/2 to 3 d. Growth is rapid and the first harvest is made after 30 d and then every 7 to 10 d for 10 or more harvests. The total yield is an average of 90,000 kg/ha (Edie and Ho 1969). In W. Java it may be cultivated in the same ponds as common carp, to which rice bran and urea are added (Djajadiredja and Jangkaru 1978), but in Thailand it is usually grown in highly eutrophic canals and borrow pits along the sides of highways and occasionally in ponds with fish culture. In Thailand, where the growing season is continuous throughout the year, the crop is propagated by vegetative cuttings and is grown on water at all times. Annual yields in Thailand and other tropical countries probably far exceed those of Hong Kong because of year round cultivation, but data are lacking.

Family Cyperaceae

*Cyperus,* sedge, is an emergent plant of which some species, e.g., *C. esculentus,* are widely cultivated for their edible tubers, which are often erroneously named

Figure 3. Water spinach, *Ipomoea aquatica,* cultivated as a vegetable in a eutrophic canal, Thailand.

water chestnuts (Cook et al. 1974; Biotrop 1976).

*Eleocharis dulcis (E. tuberosa)*. Chinese water chestnut or matai has corms or tubers which are produced in large quantities on underground rhizomes towards the end of the growing season. The corm has a crispy, apple-like texture with a sweet taste. It is used as an ingredient in chop suey and Chinese meat and fish dishes, and in China is also eaten like fresh fruit. The plant is widespread from Madagascar to India, S.E. Asia, Melanesia and Fiji, but is never cultivated in most of its geographical range. Occasionally, it is used as a wild source of food in Java and the Philippines. The corm is high in carbohydrate and low in protein (1.4 to 1.5%) (Hodge 1956; Ruskin and Shipley 1976). It has been cultivated in China for centuries, where strains with large, sweet corms were developed. It is grown in China, Taiwan and Hong Kong as a paddy crop in rotation with other aquatic crops, e.g., rice, lotus or arrowhead. Small seed tubers are raised in nursery beds, transplanted, and then the field is flooded. Heavy fertilization is needed using lime, peanut cake, plant ash, animal manure and night-soil. It requires a long warm growing season but is not fully mature until frost kills the green culms. The yield is greater than 7 t tubers/ha (Ruskin and Shipley 1976); according to Hodge (1956), it is about 18 to 37 t/ha. It has been introduced for trials into Australia, Java, Indo-china and the Philippines, but there is no indication that its culture has become important outside China. There has been interest in establishing it in the warmer areas of the U.S.A. as a new crop, since it brings high prices (Hodge 1956). Recently, new high yielding, sweet tasting, cultivars have been developed in the U.S.A., which could help it to become a new agricultural crop in many countries (Ruskin and Shipley 1976).

Family Fabaceae (Leguminosae)

*Neptunia oleracea* roots in marshy soil but it floats on open water (Fig. 4). The young plants are cooked as a green vegetable but there are no data on its productivity. It may be rich in protein, however, since it is a legume (Ruskin and Shipley 1976). It is cultivated in Thailand in the same way as *Ipomoea aquatica*, in eutrophic canals and borrow pits, and occasionally in ponds, usually with fish culture. Since it is mentioned as a vegetable by neither Subramanyam (1962) nor Cook et

Figure 4. *Neptunia oleracea*, a legume, cultivated as a vegetable in a eutrophic borrow pit, Thailand.

al. (1974), it is probably less commonly grown as a vegetable than *Ipomoea aquatica*, as indeed is the case now in Thailand.

Family Haloragaceae

*Myriophyllum aquaticum*, water milfoil, is a submersed species originating from S. America. It is often considered a nuisance, but in Java it is cultivated and the tips of the shoots are eaten as a vegetable (Cook et al. 1974).

Family Hydrocharitaceae

*Blyxa lancifolia* is a submersed plant, the leaves of which are eaten as a vegetable (Biotrop 1976). In Thailand, according to Suwatabandhu (1950), it is one of the most popular vegetables and is eaten raw with certain kinds of fish.

*Ottelia alismoides* is a submersed plant that invades rice fields. The entire plant, except the roots, is cooked as a vegetable (Suwatabandhu 1950; Biotrop 1976; Ruskin and Shipley 1976). The fruit may also be cooked and used for human food in Thailand (Suwatabandhu 1950).

Family Lemnaceae

*Wolffia arrhiza*, the smallest flowering plant, is a floating, rootless plant that rarely exceeds 1 mm in size, but is used as a vegetable in N. Thailand, Burma and Laos (Bhanthumnavin and McGarry 1971; Biotrop 1976; Ruskin and Shipley 1976). Its cultivation has been studied by Bhanthumnavin and McGarry (1971) in N. Thailand. It is grown on a small scale in rain fed ponds and no fertilizer or manure are added. The plant is in edible form from November to July when it is harvested every 3 to 4 days. From August to October the plant is in an inedible, sexually reproducing stage. The generation time in the laboratory was found to be about 4 days. The ponds averaged a yield of 0.68 $kg/m^2/wk$ over a 4 mo period. Based on a 9 mo growing season the calculated annual yield is 265 t fresh weight/ha or 10.5 t dry weight/ha. The protein content is 19.8% on a dry weight basis. In terms of annual yield, the plant produces more dry matter and several times more protein than traditional Thai crops such as rice, corn, soybean and groundnut. No attempts have yet been made to improve the yields of the crop or grow it on a larger scale.

Family Limnocharitaceae

*Limnocharis flava*, is an emergent plant native to Latin America but was introduced into tropical Asia before 1870 (Cook et al. 1974; Ruskin and Shipley 1976). The leaves, stems and flower clusters are cooked and eaten as a vegetable (Cook et al. 1974; Dassanayake 1976; Ruskin and Shipley 1976). The young leaves contain 1.0 to 1.6% protein. In Malaysia and Java it is grown in rice paddies (Ruskin and Shipley 1976). According to Djajadiredja and Jangkaru (1978) it is cultivated in ponds with common carp in W. Java.

Family Nelumbonaceae

*Nelumbo nucifera (N. speciosa, Nelumbium nelumbo)*. This is the sacred lotus flower of the Hindus (Cook et al. 1974) and the flower also has religious significance in Buddhism. It has been cultivated in China since at least the 12th century B.C. (Herklots 1972) and today is widely cultivated in Asia, though mainly for the flowers (Cook et al. 1974; Ruskin and Shipley 1976; Varshney and Singh 1976) (Fig. 5). Various parts of the plant can be used in a variety of cooked and fresh dishes. The rhizomes may be cooked in curries (Ruskin and Shipley 1976) or steamed for use in salad (Burkill 1935). In Indochina they may be eaten raw, or pickled in salt or vinegar (Burkill 1935). The rhizomes, which are marketed fresh, dry, canned, or as a fine white starch, are in demand by Chinese the world over and sell for high prices (Ruskin and Shipley 1976). When eaten young it tastes like artichokes (Burkill 1935). The protein content is about 2.7%. The seeds can be eaten raw, boiled or roasted, candied, ground to flour, or canned (Subramanyam 1962; Burkill 1935; Ruskin and Shipley 1976). In some parts of India the flowering stems and young fruits are eaten (Malik 1961) and in the Celebes the young shoots are eaten boiled and the leaves raw (Burkill 1935). There are few data on productivity. In the Punjab 62 ha are cultivated and produce 3,787 to 4,734 kg roots/ha which gives a net income of just over 1,000 rupees/ha. Since the crop does not need much cultivation, the return is attractive; the land would otherwise yield nothing (Malik 1961).

Family Nymphaceae

*Euryale ferox*, water lilly. The fruits and seeds are eaten in S. Asia (Cook et al. 1974) and the seeds are roasted and eaten in India (Subramanyam 1962). According to Burkill (1935), the starchy seeds are used as a light food for invalids in India and China.

*Nymphaea lotus*, water lilly. The stem is sometimes eaten as a vegetable (Biotrop 1976). According to Burkill (1935), the seeds are eaten in India as famine food and by the poorest people regularly. The rhizomes are eaten cooked in India and China, and sometimes the young fruits are eaten as a salad.

Figure 5. Lotus, *Nelumbo nucifera*, cultivated for flower buds and human food, Thailand.

*Nymphaea nouchali*, water lilly. In certain regions of India, the rhizomes, petioles and peduncles are eaten, and the seeds in times of scarcity (Subramanyam 1962).

*Nymphaea stellata*, water lilly. According to Biotrop (1976), the stem is eaten as a vegetable. In India the flower stalk is eaten as a vegetable (Varshney and Singh 1976) and the roots and seeds as famine food (Burkill 1935).

*Victoria amazonica*. The seeds of this water lilly, which occurs in S. America, are very rich in starch, and are used to make a flour (Cook et al. 1974).

*Victoria cruziana*. The seeds are used in the same way as those of *V. amazonica* (Cook et al. 1974).

Family Onagraceae

*Ludwigia adscendens*. According to Biotrop (1976), the young shoot and young leaves are used as vegetables.

*Ludwigia repens*. The young shoot and leaves are used as green vegetables in Thailand (Suwatabandhu 1950).

Family Poaceae or Gramineae

*Hygroryza aristata*. The grains of this floating grass are said to be eaten by poor people (Cook et al. 1974).

*Oryza sativa*, rice. Rice is the most important crop plant in the world and is usually grown as an aquatic annual (Cook et al. 1974). Floating or deep water rice, which is often completely submerged for up to 30 d, is grown mostly by subsistence farmers in river valleys where the water depth in the growing season can be as much as 6 m deep. Research on this variety has only just started, but yields similar to unimproved, conventional varieties have been obtained (Ruskin and Shipley 1976). This variety may have potential for integrated rice and fish culture.

*Zizania aquatica*, wild rice. Wild rice is the native cereal of Canada and the northern U.S.A. (Cook et al. 1974; Ruskin and Shipley 1976) and the rather large grains were gathered and eaten by N. American Indians (Herklots 1972). Apparently, it has recently been cultivated (Ruskin and Shipley 1976). It has been introduced into suitably high elevations in the tropics (Ruskin and Shipley 1976).

*Zizania latifolia (Z. caduciflora)*, is closely related to *Z. aquatica*. It is cultivated in Japan, China and Vietnam as human food (Herklots 1972; Cook et al. 1974; Ruskin and Shipley 1976). The plant is also attacked by a fungus which hinders stem elongation and flowering and causes the stem to thicken; the latter is cooked and eaten like asparagus (Cook et al. 1974).

Family Podostemaceae

*Dicraeanthus* spp. There are 4 species of the plant in W. Africa. The floating stems and leaves are used locally as a salad (Cook et al. 1974).

*Eichhornia crassipes*, water hyacinth. According to Burkill (1935), the young leaves, petioles and flowers are sometimes eaten in Java after being steamed or cooked, but can cause upleasant itching. During the Japanese occupation of the Philippines, the soft white buds were eaten raw, as salad, or as an ingredient for vegetable dishes, but it is doubtful if the people involved would do it again in times of plentiful food supplies (Villadolid and Bunag 1953).

Family Pontederiaceae

*Monochoria* spp. According to Cook et al. (1974), the leaves of *Monochoria* spp. are commonly eaten as a vegetable. Biotrop (1976) reported that the leaves and stems, and Dassanayake (1976) that the leaves of *M. vaginalis* are eaten as a vegetable. In India all parts of *Monochoria hastata* except the roots furnish a relished dish (Subramanyam 1962).

Family Potamogetonaceae

*Potamogeton* sp., pond weed. Varshney and Singh (1976) reported that the rhizomes are used as food by local people in India.

Figure 6. Harvesting water chestnut, *Trapa* sp., cultivated in a borrow pit, Thailand.

Family Sphenocleaceae

*Sphenoclea zeylandica*. The species is often regarded as troublesome weed in rice fields but in Java the young plants are eaten (Cook et al. 1974).

Family Trapaceae

*Trapa* spp., water chestnut. The genus is native to Asia and tropical Africa but there is little agreement as to whether there is 1, 3 or up to 30 species in the genus (Cook et al. 1974). Specific epithets used for species edible to humans are *T. bicornis, T. bispinosa, T. incisa* and *T. natans* (Subramanyam 1962; Herklots 1972; Biotrop 1976; Ruskin and Shipley 1976). The nut or kernel of the spiny fruit is eaten raw or cooked or is ground into flour, which is used for various preparations (Malik 1961; Subramanyam 1962). The nut contains much starch and fat, and forms a staple food in Asia (Cook et al. 1974). The fresh kernel has about 3% protein (Herklots 1972). *Trapa* is common in almost all states in N. India and is extensively cultivated in some (Malik 1961). According to Subramanyam (1962), it is extensively grown in India. It is cultivated in most of E. Asia (Ruskin and Shipley 1976). Some countries, e.g. Indonesia, in addition to growing their own crop, import nuts from China (Cook et al. 1974) (Fig. 6). The plant is grown in waterlogged areas in India and the yield varies, but may be 14,000 kg/ha if the crop is good, which gives a net income of about 1,200 rupees/ha. Yields may fall, however, due to a beetle infection (Malik 1961).

Family Typhaceae

*Typha angustifolia*, cattail. According to Biotrop (1976), the rhizome is sometimes eaten. In Sind, Pakistan, a curious yellow cake called "bur" is prepared from the flowers and eaten by all classes of people (Subramanyam 1962).

LEAF PROTEIN EXTRACTION

A more recent development is the preparation of leaf protein, which involves crushing the leaves or shoots of freshly harvested plants, pressing the juice from the pulp and coagulating the protein in the juice by heating. The curd of protein is filtered out and dried. It is suitable for human diets (Boyd 1974). Boyd (1968a) evaluated the extractability of proteins from 25 species of aquatic macrophytes and found that the leaf protein was similar in chemical composition to leaf protein from crop plants. However,because of the numerous processing and refining steps, leaf protein is considerably more expensive than traditional protein sources (Bates and Hentges 1976).

Several species of aquatic macrophytes are used as livestock fodder but their high moisture content is a major constraint. Also, there appears to be a palatability problem which may restrict the amount of plant material consumed. The conversion of aquatic macrophytes into silage has been proposed as a method for reducing or eliminating the need for drying the plants.

## SPECIES USED AS FODDER

Several species of aquatic macrophytes are used as animal fodder. In Malaysia, Chinese fish farmers seine algae once or twice per week, mash them and feed them to pigs and ducks (Hora and Pillay 1962). In India, village scale experiments are being conducted on feeding poultry on the blue green alga *Spirulina platensis* (Seshadri 1979), and in Mexico *Spirulina maxima* produced in mass culture is being used as a supplement for chick feed (Ruskin 1975). *Azolla pinnata* is widely used to feed pigs and ducks (Burkill 1935; Suwatabandhu 1950; Moore 1969; Cook et al 1974) and also cattle in Vietnam (Moore 1969). It is also used to feed livestock in mainland China (Hauck 1978). Another fern, *Salvinia* sp., is also collected and fed to pigs and ducks in Indo-China (Moore 1969). *Pistia stratiotes* is used for pig, cattle, and duck food (Fig. 7) (Burkill 1935; Suwatabandhu 1950; Moore 1969; Varshney and Singh 1976) and is often encouraged by Chinese farmers in Malaysia and Singapore to grow on fish ponds (Burkill 1935). The same species is also cultivated in China for animal fodder (Hauck 1978).

The tubers of several species of *Aponogeton* are eaten by livestock (Cook et al. 1974). *Lemna* spp. are fed to pigs and ducks (Moore 1969; Varshney and Singh 1976). *Typha* sp. and *Nymphaea stellata* are used as fodder in India (Varshney and Singh 1976). *Hydrilla verticillata* is used as pig and duck feed (Burkill 1935; Varshney and Singh 1976). Alligator weed, *Alternanthera philoxoides,* is readily eaten by cattle (Alford 1952; Göhl 1975) and is the most widely cultivated aquatic macrophyte for animal food in the northern provinces of China due to its tolerance to lower temperatures (Hauck 1978). *Ceratophyllum demersum* (Suwatabandhu 1950) (Fig. 8), *Limnocharis flava* (Cook et al. 1974), and the vegetable part of *Sagittaria* spp., (Cook et al. 1974; Ruskin and Shipley 1976) are fed to pigs. *Sesbania sesban* is used as a fodder plant on land subject to flooding and is especially valuable in saline areas (Cook et al. 1974). The grasses *Coix aquatica, Paspalidium geminatum, Panicum geminatum, Leersia hexandra* (Subramanyam 1962) and *Hygroryza aristata* (Subramanyam 1962; Cook et al. 1974) are readily eaten by cattle. *Ipomoea aquatica* is commonly given to pigs (Burkill 1935; Le Mare 1952; Edie and Ho 1969; Ruskin and Shipley 1976) and is also used as cattle fodder (Ruskin and Shipley 1976).

Water hyacinth deserves special mention since it causes problems in many areas but it is used as animal fodder (Suwatabandhu 1950; Subramanyam 1962). In India it is reported that feeding buffaloes about 7 kg water hyacinth/d increases their milk yield by 10 to 15% although the milk is rather watery and the butter made from it does not possess the proper consistency and flavor (Anon. 1951). In the Sudan (Davies 1959), India (Sahai and Sinha 1970; Anon. 1973) and Bangladesh (Anon. 1973), it is used as cattle fodder during the dry season, despite its low grazing value, since it may be the only green vegetation available. Rather surprisingly, water hyacinth is cultivated as fodder in many areas in Asia (Burkill 1935; Hora 1951; Chomchalow and Pongpangan 1976). In Malaysia and Singapore (Hora 1951) and Thailand, the washings from the pig sties often drain into fish ponds where water hyacinth is grown for pig fodder. The demand in Central and S. China and Hong Kong for water hyacinth as pig fodder is so great that its growth is checked (Hora 1951); it is also cultivated for animal fodder in China (Hauck 1978).

According to Hauck (1978), aquatic macrophytes are cultivated in China to provide fodder in areas with networks of waterways. Apparently, aquatic plants provide a major portion of the animals' fodder requirements and thus relieve that extra pressure on land for fodder raising. In Kashmir, some aquatic macrophytes are harvested for fodder on an irregular basis (Zutshi and Vass 1976).

## FRESH AND DEHYDRATED MATERIAL AS FODDER

Aquatic macrophytes compare favorably on a dry weight basis with conventional forages (Boyd 1974), but to use them efficiently as animal fodder, they should be partially dehydrated, since typically water weeds contain only about 5 to 15% dry matter compared to 10 to 30% for terrestrial forages (Ruskin and Shipley 1976). Because of the high moisture content, animals cannot consume enough to maintain their body weight.

Attempts have been made to feed fresh water hyacinth to animals, since cattle and buffalo have been observed to eat it (Chatterjee and Hye 1938). Animals in India fed only fresh water hyacinth and straw showed a steady weight loss, which indicates that the diet was not even

Figure 7. Harvesting water lettuce, *Pistia stratiotes*, growing wild in a borrow pit, for duck feed, Thailand.

sufficient for maintenance. When the diet was supplemented with linseed cake, the condition of the animals was much better, and there was a slight weight gain. Chatterjee and Hye (1938) concluded from their study that a moderate use of fresh water hyacinth as fodder is permissible, but that it needs to be fed in combination with other feeds. Hossain (1959) studied the use of fresh water hyacinth in bullock diets in East Pakistan. Animals given only water hyacinth developed diarrhoea. During the monsoon season, the animals relished water hyacinth, and he was able to gradually increase the consumption of water hyacinth and decrease the other constituents of the diet until the average consumption increased to 13.6 kg of hyacinth and 1.4 kg of paddy straw only. On this diet, however, the animals lost weight, which supports the earlier conclusion of Chatterjee and Hye (1938) that fresh water hyacinth cannot become a major fodder.

A major constraint is the logistic problem of harvesting and processing plant matter which may be more than 90% water. Various mechanical devices have been developed for large scale harvesting (Robson 1974; Ruskin and Shipley 1976) but these are usually costly to purchase and operate. Velu (1976), however, described mechanical harvesters developed in India, which he claims are simple and portable and can be fabricated completely out of indigenous materials.

Once the weeds have been harvested, there is the problem of reducing their water content. Partial dehydration can be achieved by placing the plants in thin layers on sloping surfaces, or by draping them over lines and leaving them to dry in the sun. The plants must be turned at intervals to decrease decay (Boyd 1974). A problem with sun dried duck weed is that the material becomes extremely light and can be carried away by the slightest breeze (Lawson et al. 1974). Aquatic macrophytes can be sun dried to make hay in dry climates but spoilage occurs rapidly in the humid tropics (Ruskin and Shipley 1976). Kamal and Little (1970) determined the rate of weight loss from 34 kg of water hyacinth spread over an area of 1 $m^2$ during hot, dry, sunny weather, with little to no wind in the Sudan. They reported a weight, expressed as a percentage of the initial weight, of about 67% after 1 d, 46% after 2 d and 35% after 3 d. Water hyacinth hay is still bulky, however, due to the petiole, which remains round and full of air, and limits the feasibility of transportation (Göhl 1975). Hossain (1959) sun-dried water hyacinth for about 7 hr, which led to a loss of about 50% of the water. Bullocks fed on a ration containing partially dehydrated water hyacinth gained considerably in weight; the ration consisted of about 10 kg of partially dried hyacinth, 1.4 kg of paddy straw and 0.7 kg of mustard cake, although the animals ate only about 8 kg of hyacinth. Thus, it does appear that water hyacinth can support the growth of livestock, if it is partially dried and properly supplemented, and if the animals are accustomed to it.

The water content can also be reduced mechanically by chopping and pressing, but this again requires expensive machinery. Furthermore, there can be substantial nutrient losses in the press liquor, depending on the degree of pressing (Bruhn et al. 1971; Bagnall et al. 1974a; Bates and Hentges 1976). Lightweight experimental presses suitable for use in developing countries have been designed, which may be compatible with manual harvesting and with the small scale needs of animal feed in rural areas (Ruskin and Shipley 1976).

The traditional Chinese way of feeding water hyacinth to pigs involves chopping the plant (Fig. 9) and boiling it slowly for a few hours with other vegetable wates, e.g., banana stems, until the ingredients turn into a paste. Rice bran and food concentrates, e.g., copra cake, groundnut cake, which vary from place to place, and sometimes maize and salt, are added to the liquid paste (Choy and Deveraj 1958; Mahmud 1967; Göhl 1975). A common formula is 40 kg water hyacinth, 15 kg rice bran, 5 kg coconut meal, and 2.5 kg fish meal (Göhl 1975), but according to Mahmud (1967) the hyacinth only comprises 5 to 10% of the total ingredients. The method is undoubtedly effective and is widely used by Chinese farmers. Presumably, boiling the water hyacinth increases its digestability and also reduces its water content considerably. The cost of the fuel to boil the water hyacinth adds to the cost of the feed, however, and according to Mahmud (1967), pigs fed on such a feed normally take longer to reach marketweight than those fed on dry mashes. In Malaysia, feeding pigs hyacinth is becoming less common. The method would, therefore, appear to be useful only to small-scale farmers with very limited capital.

Feeding experiments have been conducted with dry aquatic macrophyte feed. Vetter (1972) fed pelleted hyacinth containing 90% dry matter to native heifer calves at 1/3 of their ration and concluded that the water plant may have some feed value, although the processing costs were high relative to the amount and

Figure 8. Harvesting *Ceratophyllum demersum* and *Najas sp.*, growing wild in a lake, for animal feed, Thailand.

Figure 9. Chopping water hyacinth, *Eichhornia crassipes,* prior to boiling for use as pig feed, Thailand.

quality of the dry feed matter produced. Hentges et al. (1972) fed cattle pelleted diets containing 33% organic matter of coastal bermuda grass, water hyacinth and *Hydrilla*. The yearling steers remained healthy and in positive nitrogen balance on all diets, and the apparent digestion coefficients for organic matter and crude portein were comparable for all three diets. According to Bagnall et al. (1974b), cattle and sheep voluntarily consumed diets containing processed water hyacinth but animal performance was best when the amount of water hyacinth fed was less than 25% of the complete diet on a dry organic matter basis. Water hyacinth meal, made by drying whole green plant to less than 15% moisture content, was able to provide 10 to 20% of the diet of beef cattle, but beyond this amount the animals suffered from mineral imbalance due to high levels of potassium, iron and magnesium (Wolverton and McDonald 1976).

Liang and Lovell (1971) reported low consumption by fingerlings of channel catfish, *Ictalurus punctatus,* of diets containing substantial quantities of dried aquatic macrophyte meals, which they attributed, in the case of water hyacinth, to low protein quality, quantity and palatability. Bahr et al. (1977) supplemented fish diets with 1/3 filamentous green algae by weight. The results of feeding trails with *Cyprinus carpio* were disappointing but trout growth was equal to the control diet at much less cost.

Although the results of some of the above studies are promising, the nutritive value per unit dry matter is too low to bear the cost of dry feed preparation, which is high. The cost of artificial drying, grinding, formulating with other feed to improve palatability, and pelleting, make the cost of feed from aquatic macrophytes considerably higher than other quality feeds (Frank 1976). Furthermore, dried water hyacinth flows poorly and is very frictional and abrasive, causing very low pelleting rates and a very high energy requirement (Bagnall et al. 1974b).

It thus appears that livestock feeds of high quality can be made from certain aquatic macrophytes but the cost of harvesting, transportation and processing by mechanical techniques prohibits commercial exploitation, even in developed countries (Boyd 1968a, 1974). If cheap, manual labour were used to harvest the plants, the excessive moisture content of even partially dehydrated plant material would prohibit the cost of transportation to a central processing plant. Expensive mechanical means would still be needed to further dehydrate the material and process it into dry, commercial, feed formulations.

PALATABILITY

The palatability of aquatic macrophytes, in addition to their high moisture content, restricts the ability of animals to obtain adquate nourishment. The palatability of feed processed from aquatic macrophytes compares poorly with that of most other conventional feeds. Charterjee and Hye (1938) reported that cattle were reluctant to eat water hyacinth in feeding trials. When only pressed, dried water hyacinth was offered to steers, the consumption was less than 1% of their body weight (Bagnall et al. 1974b). Hossain (1959) found that bullocks were reluctant to consume water hyacinth in the dry season but that consumption increased when the plant grew luxuriantly in the monsoon season. According to Frank (1976), livestock will eat aquatic macrophytes if mixed with molasses, but a reduced intake and loss of weight occurs if the proportion of weeds is too high. As little as 5% water hyacinth in the diet of pigs led to a depression in weight and 30% water hyacinth in the diet reduced the weight gain by 94%. *Hydrilla* was more palatable than water hyacinth, since the weight gain of pigs fed a diet containing 20% *Hydrilla* was reduced by only 25% (Frank 1976). Linn et al. (1975b) reported a low palatability of aquatic macrophytes to lambs and neither drying nor ensiling appeared to improve palatability.

## NUTRITIONAL VALUE

None of the feeding tests reported in the literature produced evidence of toxins in aquatic macrophytes (Anon. 1973; Bagnall et al. 1974b; Frank 1976; Ruskin and Shipley 1976). Potentially toxic substances such as nitrates, cyanides, oxalates, tannins and dicoumarins are present at times in aquatic macrophytes, but they also occur in many terrestrial forages, so that in general aquatic plants are no more hazardous to livestock than conventional forages (Ruskin and Shipley 1976). Boyd (1968a), however, reported a concentration of tannins of 10% or more of the dry weight in some species of aquatic macrophytes, which would greatly impair the digestibility of their protein. In some regions of the upper Waikato River, New Zealand, the waters are rich in arsenic, which is accumulated by aquatic macrophytes; values greater than 1,000 mg/kg (1,000 ppm) dry weight have been recorded, which would be dangerous to animals (Chapman et al. 1974).

Water hyacinth contains crystals of calcium oxalate (Nag 1976), which have been considered to be the cause of low palatability (Göhl 1975). Since oxalate combines with calcium and prevents its use by the animal, this could lead to a calcium deficient diet, but water hyacinth also contains considerable amount of calcium, which should make up for any losses caused by oxalates (Anon. 1973).

Aquatic macrophytes generally have a high mineral content, which has been considered as the reason why animals refuse to eat them in large quantities. The mineral content can be high, up to 60%, depending on the species and on the condition of the waterway, if the plant is covered in sand, silt and encrusted carbonate. The mineral content within the plant tissue can affect its value as feed. In Florida, the concentrations of P, Mg, Cu, Zn, and Mn in aquatic macrophytes were similar to those of terrestrial forages but the concentrations of Na, Fe and K were 10 to 100, 4 to 19 and 3 to 6 times greater, respectively (Ruskin and Shipley 1976). The inability of beef cattle to eat more than 10 to 20% of the diet as water hyacinth meal was attributed to high levels of K, Fe, or Mg (Wolverton and McDonald 1976). Chatterjee and Hye (1938) postulated that the reluctance of cattle to eat fresh water hyacinth in their feeding trials may be due to a high content of potash and chlorine. It has been reported, however, that the palatability of *Myriophyllum spicatum* was improved by heat treatment which presumably eliminated an objectionable, natural, volatile substance (Frank 1976).

## SILAGE

A promising technique to eliminate the expense of artificially drying aquatic macrophytes is to convert them into silage (Anon. 1973; Frank 1976; Ruskin and Shipley 1976). According to Ruskin and Shipley (1976), ensiling aquatic macrophytes could become important in the humid tropics where it is difficult to sun dry plants to make hay. For successful ensiling of aquatic macrophytes, the water content must usually be less than 80%, otherwise the silage turns liquid and foul smelling. According to Ruskin and Shipley (1976), water hyacinth silage can be made with 85 to 90% moisture content since the fibre retains water well and thus the material does not putrefy, but Bagnall et al. (1974a) found that chopped water hyacinth alone could not be made into silage since it putrefied and that 50% or more of the water had to be pressed from the hyacinth before it could be made into acceptable silage. The aquatic macrophytes can be wilted in the shade for 48 hours (Göhl 1975), or chopped and pressed to remove some of the water (Ruskin and Shipley 1976). Since silage is bulky, the silos should be located near the animals and the supply of aquatic plants (Ruskin and Shipley 1976).

To make silage, the aquatic macrophyte is chopped into small pieces and firmly packed into a silo to produce oxygen-free conditions. Putrefaction is avoided since material is preserved by organic acids such as lactic and acetic acids, which are produced during anaerobic fermentation. The process takes about 20 d, after which the pH falls to about 4. Aquatic plants are often low in fermentable carbohydrates so it is necessary to add either sugar cane, molasses, rice bran, wheat middlings, peanut hulls, cracked corn, dried citrus pulp, etc., to avoid putrefaction. Silage made from water hyacinth alone is not acceptable to livestock, but the quantity consumed by cattle increases as the level of added carbohydrate is increased, although the addition of sugar cane molasses alone does not improve acceptability (Bagnall et al. 1974b; Frank 1976). The most acceptable water hyacinth silages to cattle contain 4% dried citrus pulp or cracked yellow dent corn (Bagnall et al. 1974a; Baldwin et al. 1974). Silage treated with formic acid as a preservative (about 2 ℓ acid/t pressed water hyacinth) is usually superior to untreated silage as cattle feed. Studies with other organic acid preservatives, e.g., acetic and propionic acids, have also been successful (Anon. 1973). Added carbohydrate also functions as an absorbent material which is necessary because of the high water content of the weed. If highly absorbent additives could be found, this may eliminate the need for preliminary dehydration (Ruskin and Shipley 1976).

Although silage made from some aquatic macrophytes is relished by livestock used to high grade diets, the nutritive value is low. Agrupis (1953) made water hyacinth silage with molasses as an additive. The cattle were reluctant to eat the hyacinth silage at first, but after eating silage made from mixtures of para grass and hyacinth, they relished water hyacinth silage, although the silage contained 90.7% water. Loosli et al. (1954) also made water hyacinth silage with molasses, which was palatable to sheep, but had low nutritive value due mainly to a high water content of 87.6 to 93.7%. The sheep were unable to eat enough silage to maintain their weights unless feed concentrates were also fed. Linn et al. (1975b) also reported that lambs fed diets of ensiled aquatic plants lost weight. Chhibar and Singh (1971) ensiled water hyacinth and paddy straw in a ratio of 4:1 and added molasses at 70 kg/t. The fresh silage was 79.4% water but the digestibility was low. In feeding trials there was no loss of weight of cattle, which, therefore, derived their maintenance requirements from the silage, but for growth it would be necessary to feed supplements. Thus, as stated by Loosli et al. (1954), it does not seem worthwhile preparing aquatic macrophyte silage unless other feeds are scarce or very expensive. Perhaps a mixture of rice straw and water hyacinth would make a suitable silage for maintaining animals during periods of feed shortage.

## Recycling Wastes into Aquatic Macrophytes

ANIMAL WASTES

Integrated farming systems involving recycling livestock manure into aquatic macrophytes for use as fodder have been in operation in Asia for a long time. Chinese farmers typically feed pigs on water hyacinth, which has been grown on fish ponds (Fig. 10) fertilized by pig manure (Hora 1951). In Malaysia, a similar system utilized water spinach, *Ipomoea aquatica* as the aquatic macrophyte (Le Mare 1952). In Thailand (Fig. 11), there is an integrated farm in which poultry are reared above a fish pond on which duckweed is grown to feed the poultry. Duckweed also is often cultivated in Asia in special ponds fertilized by animal manure for feeding to grass carp (Fig. 12). In India, experiments are now being conducted at the village level (Fig. 13); animal manure is fed into a biogas digester and the slurry is used to fertilize ponds in which the blue green alga *Spirulina platensis* is raised for poultry feed (Seshadri 1979). The above integrated systems have great potential and warrant more detailed study since they essentially convert animal manure into human food.

Recently, there has been considerable interest in the U.S.A. in using duckweed to recycle the wastes generated by animal feedlots. Duckweeds grow well on animal waste lagoons and could be grown without displacing other crops. If duckweed could be grown on animal waste lagoons, harvested and fed to the animals associated with the lagoon, it could at least partially offset the cost of food, in addition to improving the water quality of the wastewater effluent (Truax et al. 1972). The problem of waste disposal from animals is a serious problem in the U.S.A. where the total domestic stock is estimated to generate $1.8 \times 10^9$ t (Culley and Epps 1973). Since the animals are concentrated in small areas in feedlots, waste recycling, involving the extraction of nutrients from the wastes to produce animal feeds, is feasible. Furthermore, there are many lagoons in existence for treatment of animal wastes, e.g., in Louisiana alone there are about 200 lagoons for agricultural waste management and the number is rising (Myers 1977).

Figure 10. An integrated farm in which water hyacinth, *Eichhornia crassipes*, is grown on a fish pond for pig feed, Singapore.

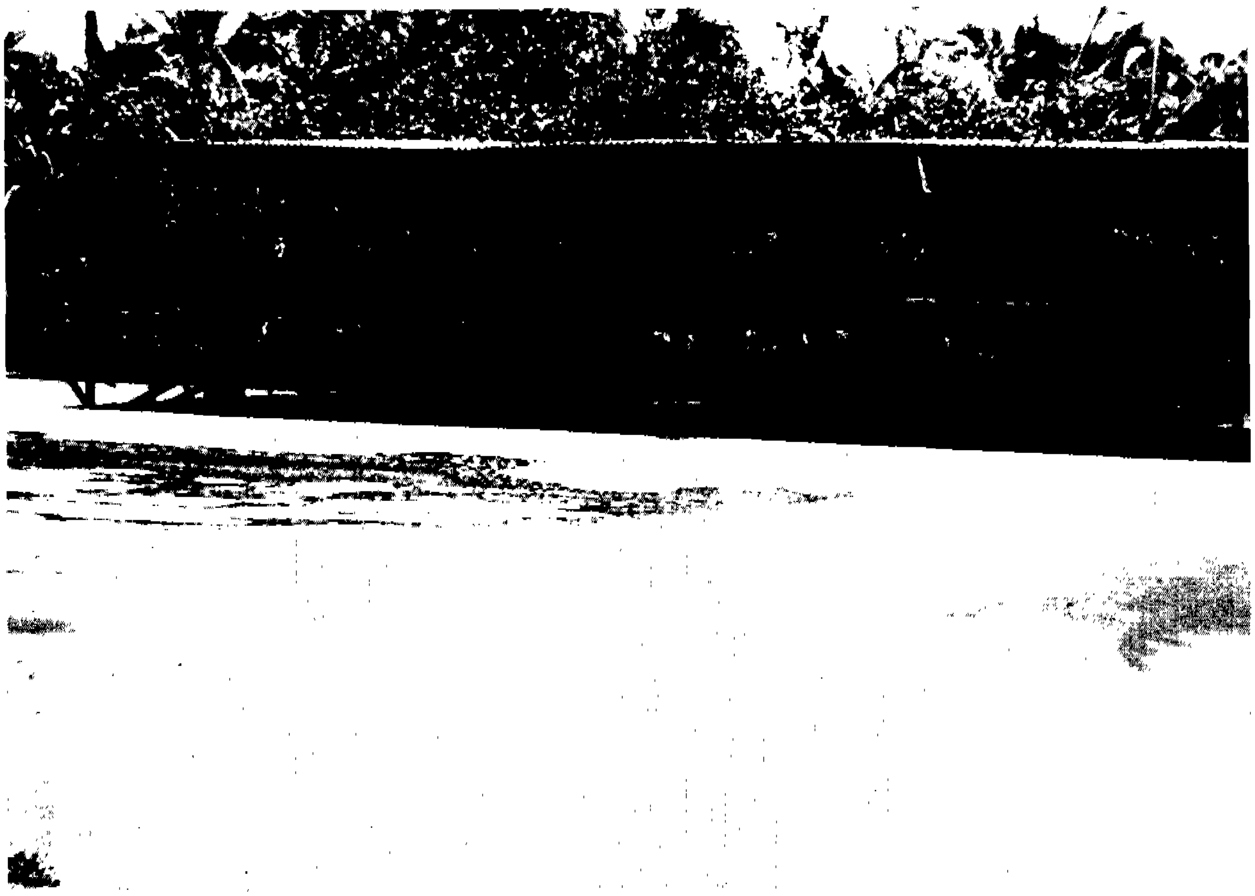

Figure 11. An integrated farm in which duckweed, *Lemna* sp., is grown on a fish pond for poultry feed, Thailand.

Duckweed is an ideal plant for an aquatic macrophyte-livestock integrated system since it has a high content of good quality protein and a rapid growth rate. The crude protein content of various species of duckweed reported in the literature varies from a low of 7.4% to a maximum of 42.6%, and there is good evidence that the higher protein levels are associated with nutrient rich waters (Truax et al. 1972; Culley and Epps 1973; Myers 1977; Hillman and Culley 1978). The crude protein content of *Spirodela oligorrhiza* grown on an anaerobic swine waste lagoon varied from 35.8 to 40.9%, which is much greater than the protein content of duckweed from natural waters (Culley and Epps 1973). The mean crude protein content of various duckweed species grown on cattle wastes in one study was 36% (Myers 1977), which is much higher than for alfalfa (17.8-20.0%; Truax et al. 1972; Culley and Epps 1973) and is similar to soybean, 37% (Culley and Epps 1973). The fat and fibre content compares favorably with that in animal feeds while Ca, P and ash values are higher. It is also fairly high in xanthophyll and carotene (Truax et al. 1972; Culley and Epps 1973). In terms of essential amino acids, methionine and lysine are generally limiting in poultry feedstuffs; duckweed is a better source of lysine and arginine but is slightly lower in methionine. Duckweed, however, is higher in protein content than alfalfa and would provide more of all three amino acids on an equal weight basis (Truax et al. 1972).

The productivity of duckweeds calculated from data reported in the literature varies from 9.4 to 39.0 t dry weight/ha/yr but the lowest value was obtained when temperatures were low and is probably not representative of what could be achieved under tropical conditions (9.4 t/ha/yr, Culley and Epps 1973; 19.2 t/ha/yr, Stanley and Madwell 1975; 14.5, 15.3, 27.0 t/ha/yr, Myers 1977; 17.6 t/ha/yr, Hillman and Culley 1978; 39.0 t/ha/yr, Hepher and Pruginin 1979). If the low value of Culley and Epps (1973) is excluded, the average, extrapolated, annual productivity is 22.1 t dry weight/ha/yr.

According to a laboratory study by McLay (1976), *Wolffia, Lemna and Spirodela* had similar growth rates of population size over a range of pH, but the growth of biomass of *Lemna* and *Spirodela* were 6.6 and 17 times greater than *Wolffia*, respectively. It thus appears that the larger the duckweed thallus, the greater the rate of biomass increase, which suggests that perhaps attention should be focused on *Spirodela*.

Since duckweeds have a high moisture content, varying from 88 to 97% (Culley and Epps 1973; Myers 1977), the cost of transportation would be a problem. Several animals, however, readily take fresh duckweed, so it could be transported and used within a farm complex. Hillman and Culley (1978) described a hypothetical duckweed-dairy farm sytem in Louisiana. The daily waste produced by a 100 head dairy herd (approximately 4.5 t) is used first to generate methane, after which the slurry is pumped into a 4 ha lagoon. The daily yield of 305 kg dry weight of duckweed through an 8 mo growing season would supply each cow with about 3.1 kg of duckweed or 1.1 kg of protein (assuming crude protein of duckweed 37% of dry weight), which is about 60% of the 1.8 kg normal daily requirement. Although the water content of fresh duckweed is much higher than usual feeds, it contains only about 40.5 of the 113.6 ℓ of the daily water normally used by a dairy cow. Since cows will accept up to 75% of the total dry weight of their feed as duckweed with no ill effects, duckweed could supply an even greater proportion of the daily ration if available.

Duckweeds can be readily harvested by skimming with a rake or by seining with a net. It has been suggested that duckweeds be harvested *in situ* by a herbivorous fish such as the grass carp, but such a system may be difficult to manage (*vide* section on Aquatic Herbivores below).

HUMAN, INDUSTRIAL AND AGROINDUSTRIAL WASTES

The use of aquatic macrophytes to treat domestic and certain industrial wastes was pioneered by Seidel and her colleagues in W. Germany. They used emergent macrophytes such as the bulrush, *Scirpus lacustris*, and the reedgrass, *Phragmites communis*, to treat a wide variety of domestic, industrial and agroindustrial effluents. The aquatic macrophytes remove heavy metals and organic compounds from the wastewater which leads to a high degree of purification (Seidel 1976), but also means that the subsequent use of the emergent vegetation as livestock fodder could be dangerous due to the possibility of contaminating pathogenic organisms and toxic chemicals. The same system has been utilized in the Netherlands to treat human wastes on camp sites (De Jong 1976) and similar systems are being studied in the U.S.A. for treatment of domestic waste water (Spangler

Figure 12. Duckweed, *Lemna* sp., cultivated by fertilizing with pig manure for feeding to grass carp, Malaysia.

et al. 1976; Whigham and Simpson 1976; Boyt et al. 1977).

The recycling of agroindustrial wastes into emergent aquatic macrophytes is much safer. In W. Germany, the effluent of a sugar factory was treated by aquatic vegetation and the stems of the bulrushes ground up. They were used to feed 10,000-20,000 ducks per year since they are rich in protein and minerals (Seidel 1976). Decades ago farmers in Finland used bulrushes as fodder for cows and sheep but this practice fell into disuse through the development and mechanization of agriculture. Recent feeding trials with chickens, however, revealed that birds fed on bulrush produced more eggs, which were bigger, had harder shells, and yellower yolks (Pomoell 1976). It appears that the recycling of agro-industrial wastes free from pathogens or toxic chemicals into emergent aquatic vegetation, could have great potential for use as animal fodder in tropical developing countries.

Recently there has been a great deal of interest in the U.S.A. in the use of floating aquatic macrophytes to reduce the concentration of phytoplankton in the effluent from stabilization ponds, and to remove nitrogen and phosphorus from the water (Sheffield 1967; Yount and Crossman 1970; Steward 1970; Boyd 1976; Wooten and Dodd 1976; Wolverton et al. 1976; Cornwell et al. 1977; Wolverton and McDonald 1979a, 1979b). The principle behind the method lies in the ability of the macrophyte, usually water hyacinth, to eliminate the phytoplankton by shading the water column, and to take up the nutrients released by phytoplankton decay.

The quantities of nutrients potentially removable by aquatic macrophytes are prodigious, and can be calculated from plant yield and mineral composition data (Steward 1970). Under favorable conditions, 1 ha of water hyacinths can produce 600 kg of dry plant matter/d (Wolverton et al. 1976), which can be extrapolated to 219 t/ha/yr with a year-round growing season. If a N and P content of 4.0% and 0.4% dry weight, respectively, are used (Steward 1970), then 1 ha of water hyacinth has the potential for removing 8,760 kg of N and 876 kg of P/yr, respectively. The water hyacinth, however, also accumulates heavy metals (e.g., Pb, Ni, Zn, Cr, Hg), from the water, and metabolized phenol (Wolverton and McDonald 1976; Wolverton and Mckown 1976; Dinges 1978). Hence it may not be suitable for livestock fodder.

It has been suggested that duckweeds, which have a greater potential use as animal fodder, should be grown using sewage effluents rather than water hyacinth (Harvey and Fox 1973; Sutton and Ornes 1975). It may be difficult, however, to utilize any floating aquatic macrophyte produced on domestic sewage due to pathogen problems and the accumulated toxic chemicals. These problems would probably be alleviated if the plants were grown on effluent which had already undergone at least secondary treatment, and if the domestic sewage was kept separate from industrial effluents containing toxic chemicals. Growing aquatic macrophytes for food on treated wastewater is apparently acceptable to some extent at least in the U.S.A. since about 10 ha of rice in Kansas are irrigated with treated wastewater (Sullivan 1974). In Taiwan, duckweed for use in feeding ducks and young grass carp is cultivated in shallow ponds fertilized with human wastes (Fig. 14). The weed is sold at about NT$2 per catty (US$1 = NT$36; 1 catty = 600 g; T.P. Chen, pers. comm.). Thus, there is a system already in operation in Asia in which human wastes are used to produce macrophytes for livestock fodder although data are not available.

Figure 13. The blue green alga, *Spirulina platensis*, cultivated partly on biogas slurry for poultry feed, India.

Figure 14. Harvesting duckweed, *Lemna* sp., fertilized with waste water, for feed, Taiwan.

## Aquatic Macrophytes as Fertilizers

Where inorganic fertilizers are too expensive, unavailable or are in short supply, it may be profitable to assess the use of aquatic macrophytes as organic fertilizers. There are several possible ways in which aquatic macrophytes may be used as organic fertilizers, namely, as mulch and organic fertilizer, ash, green manure, compost, or biogas slurry.

### MULCH AND ORGANIC FERTILIZER

Mulching involves the laying of plant material on the surface of the soil to reduce evaporation and erosion, to smother weeds, and for temperature control. Both sand and clay soils need conditioning to make them productive; sand needs organic matter and nutrients, and clay needs texturing to make it friable. Working plant material into the soil improves its texture, and also, by acting as manure, improves the nutrient content.

Several species of aquatic macrophytes are used as manure: *Pistia stratiotes* (Burkill 1935; Suwatabandhu 1950); *Hydrilla verticillata* (Suwatabandhu 1950; Subramanyam 1962; Cook et al. 1974; Varshney and Singh 1976); *Aeschynomeme* spp., (Cook et al. 1974), *Salvinia* spp., (Williams 1956; Varshney and Singh 1976) and *Eichhornia crassipes* (Finlow and McLean 1917; Day 1918; Burkill 1935; Basak 1948; Subramanyam 1962; Varshney and Rzóska 1976; Gupta and Lamba 1976). The local population in Kashmir also harvests some aquatic macrophytes on an irregular basis as manure (Zutshi and Vass 1976).

Several authors mention the high potash content of water hyacinth, which in rotted plants is several times higher than that of farm yard manure (Finlow and McLean 1917). Day (1918) reported a variation in potash content, as $K_2O$, of 2.0 to 5.5% for plants varying in moisture content from 9.2 to 13.2% water. Finlow and McLean (1917) obtained a potash value of 6.9% on a dry weight basis. Water hyacinth should be partially dried before stacking or the fresh weed mixed with earth or dry plant material in the stack, since there may be a loss of 70% of the available potash and 60% of the available nitrogen from rotting hyacinth (Finlow and McLean 1917). A 25% increase in jute yield was obtained in Bangladesh when rotted water hyacinth was added to lateritic soils deficient in potash, and good results were obtained also with rotted *Pistia stratiotes* (Finlow and McLean 1917).

Water hyacinth has been used as a mulch to conserve soil moisture during the dry season in young tea plantations (Anon. 1966). Trials using water hyacinth as mulch have also been conducted in the Sudan, along the banks of the Nile, where the soils typically are heavy, cracking clays deficient in organic matter (Abdalla and Hafeez 1969; Kamal and Little 1970). The water hyacinth was laid in layers of varying thickness on top of a complete weed cover (the sedge, *Cyperus rotundus,* and Bermuda grass, *Cynodon dactylon)* to suppress them. It was found that more than 1,000 t of fresh material/ha were needed (Kamal and Little 1970). According to Abdalla and Hafeez (1969), about 60 t of water hyacinth/ha partially dried to 20% moisture were still required to burn the tops of the sedge. For good weed control the mulch should be undisturbed for 3 mo or more and after 8 to 12 mo can be worked into the soil (Kamal and Little 1970). Although the use of water hyacinth as mulch could consume large amounts of plant material in the Sudan, where there is a serious water hyacinth infestation problem, the time and labour involved in harvesting and distributing even sun dried material would probably preclude such a use, except on a small scale adjacent to water.

Ground, dried, water hyacinth was added to a number of virgin Florida soils and commercial fertilizer added at several levels. The growth of pearl millet planted in the plots was the same as that expected from equivalent quantities of similar organic matter and fertilizer added to the soil (Frank 1976). The energy required to harvest, transport and dry the aquatic weed, however, would surely preclude the commercial viability of such an operation. In Florida also, pressed water hyacinth is marketed on a small scale as a peat moss substitute in which are grown mushrooms and seedlings (Anon 1973). Thus, it appears that due to their high water content, the use of aquatic macrophytes as mulch and manure may only be a practicable proposition on a small scale and adjacent to the water course in which the weed occurs.

A more useful way to utilize aquatic macrophytes may be to use them as organic fertilizers in fish ponds. According to Ark (1959), cut pond weeds are a good fertilizer if stacked in heaps and allowed to rot before being added to the fish pond. Two to three applications of about 1,680 kg/ha/application administered at 3 mo intervals are usually sufficient to lead to the production of a good plankton bloom. This is a promising area for research.

### ASH

It has been suggested that the ash of water hyacinth may be used as a plant fertilizer (Abdalla and Hafeez

1969). There are, however, several reasons why this is not feasible: burning of the plant to ash results in a loss of nitrogen and organic matter which reduces the fertilization potential of the plant; the plant must be dried prior to burning, which restricts the practice to dry weather periods; the ash needs immediate bagging and storing to prevent it being washed away by rain or blown away by wind (Basak 1948). Thus, the cost of labour and energy required to obtain ash from aquatic macrophytes with a high water content would far exceed the value of the ash obtained as a fertilizer.

## GREEN MANURE

Green manure, in a strict sense, is plant matter cultivated specially for its fertilizer value to other crops. However, certain species of aquatic macrophytes which grow wild in rice fields and are ploughed into paddy, e.g., *Limnocharis flava* and *Sesbania bispinnosa*, are sometimes referred to as green manure (Cook et al. 1974). Thus, the distinction between aquatic macrophytes which grow wild and are used as manure or fertilizer, and green manure which is cultivated, is not always maintained. Certain types of aquatic macrophytes are cultivated as green manure or biofertilizers to add nitrogen to the soil, and this practice may be useful since it lessens dependence on commercial, inorganic fertilizer.

The cultivation of the fern *Azolla pinnata*, with its symbiotic nitrogen fixing blue green alga *Anabaena azollae*, apparently developed in N. Vietnam (Moore 1969; Galston 1975) and has spread recently to S. China (Hauck 1978). In both countries there are extension programs to increase its use in rice paddies. In N. Vietnam, just before or after rice transplanting, *Azolla* is scattered in the fields at a rate of about 10 $m^2$ of macrophyte seed/ha, and in January and February it grows along with the rice. During this time, when the mean daily air temperature is 16 to 17°C, it grow rapidly and completely covers the surface of the water. Towards the end of March, when the temperature rises to 22 to 24°C, most of the *Azolla* dies and releases nitrogen, and following the rice harvest in May and June, little or no *Azolla* remains. The *Azolla* produces about 50 tons of fresh material/ha, and assimilates more than 100 kg N/ha in the 3 to 4 mo growing period. A negligible proportion of the fixed nitrogen is released when *Azolla* is growing and it becomes available only on the death of the plant, as the water temperature rises. To carry stocks of *Azolla* through the hot season, the fern is placed in 1-m deep ponds surrounded by dense bamboo fences to provide shade. Dried pig manure and castor oil cake are added. The fern dies in April, but reappears in July, and is then cultivated for sale (Moore 1969). Galston (1975) reported that rice yields for *Azolla* seeded fields in Vietnam were 50 to 100% greater than adjoining paddies which were not seeded. According to Moore (1969), the rice yield increases due to *Azolla* vary from 14 to 40%. China has also developed the cultivation of *Azolla* on a large scale for fixing nitrogen in rice paddies, but the fern is ploughed in before the rice seedlings are transplanted. *Azolla* regenerates, but is reburied by hand to avoid competition with the rice seedlings. Phosphorus fertilizer is still applied, but the requirement for nitrogen fertilizer is reduced by 50% using *Azolla*, and the rice yield is 10 to 15% higher than when inorganic fertilizer is used alone (Hauck 1978).

Since *Azolla* is cultivated as green manure in only a limited area of Asia, there may be management problems in other areas. In Japan it is considered as a weed since it covers the rice seedlings after transplanting. Rising temperatures kill *Azolla* in N. Vietnam when the rice is growing rapidly (Moore 1969), but in China *Azolla* must be ploughed under or buried by hand (Hauck 1978). In tropical rice growing areas, it also appears that a method of killing the *Azolla* would be necessary (Moore 1969), although there may also be problems with the more elevated temperatures in tropical countries being inimical to the growth of *Azolla*. In Varanasi, India, the plant is a winter annual (Gopal 1967) and appears to be more abundant in Thailand during the cool season than at other times of the year. There are, however, some tropical strains that grow at 30 to 35°C (Hauck 1978). Experiments on a limited scale were conducted in Indonesia in World War II (Moore 1969). More experimentation is needed to determine the potential of *Azolla* in tropical areas.

Attempts have also been made to use free living, filamentous, nitrogen fixing blue green algae to improve the fertility of rice fields. Large-scale field experiments in which *Tolypothrix tenuis* was seeded into rice fields began in Japan in 1951 and average increases in rice yields of 20% were obtained (Watanabe 1960). Extensive field trials have been carried out in India where blue green algae can contribute about 25 to 30 kg N/ha/cropping season. A mixture of *Aulosira, Tolypothrix, Nostoc, Anabaena,* and *Plectonema* applied to the rice field reduces the required inorganic fertilizer N dose to obtain the same yield by about one third (IARI 1978). Research utilizing *Anabaena* and *Nostoc* in rice paddies is being conducted in China (Hauck 1978).

## COMPOSTING

One of the most promising methods to utilize aquatic macrophytes is to use them to make compost, since very little drying is needed, and transportation is not necessary if the plants are composted on shore. Furthermore, no chemicals or mechanical devices are needed (Basak 1948; Gupta and Lamba 1976; Ruskin and Shipley 1976). Compost is suitable for many developing countries where commercial fertilizers are expensive or not available and labour is plentiful (Ruskin and Shipley 1976). It has even been suggested that compost may be the most feasible product from aquatic macrophytes in the U.S.A. (Bagnall et al. 1974b; Bates and Hentges 1976). As Watson (1947) wrote about water hyacinth, "it is a wonderful plant, trapping the sunlight to build up immense stores of cellulose and intercepting the soluble salts washed out of the soil and storing them in its tissues. But to appreciate it one has to learn to appreciate compost."

The plants should be spread out and dried for a day or two to reduce their moisture and then made into a pile with soil, ash, animal or human waste. The compost pile has to be carefully made and maintained to avoid anaerobic conditions which would produce foul odours. The composting process, the details of which vary, takes usually 1 to 3 mo (Watson 1947; Basak 1948; Singh 1962; Kamal and Little 1970; Polprasert et al. 1980).

Compost contains only 1.5 to 4% N, 0.5 to 1.5% P, and 1 to 2% K, which is several times less than inorganic fertilizers. It is thought, however, that 25 to 30% of inorganic fertilizers are leached to the groundwater, whereas compost nutrients are released into the soil gradually, and are thus available throughout the growing season (Ruskin and Shipley 1976).

Compost is much bulkier than inorganic fertilizer, and since the nutrient content is lower, large quantities may be required. Thus, it is really only an attractive proposition where labour is cheap and plentiful (Ruskin and Shipley 1976). The benefit to the crop is obvious, however, and the enthusiasm in India where water hyacinth was used, was so great that not enough was left to continue further growth (Watson 1947). In Sri Lanka, the Home Gardens Division of the Department of Agriculture makes more than 80 t of compost/mo from chopped water hyacinth and city refuse, plus small amounts of ash, earth and cow manure, which is used to raise vegetable seedlings (Ruskin and Shipley 1976).

Perhaps the most efficient way to utilize compost is to add it to fish ponds as an organic fertilizer to raise plankton, rather than applying it to crops. This was suggested by Singh (1962) although no details were given. Mitra and Banerjee (1976) conducted laboratory experiments with composts of *Spirodela polyrrhiza, Hydrilla verticillata,* and *Eichhornia crassipes.* The composts were added to jars of water and the phytoplankton and zooplankton populations estimated. At the end of the experiment, plankton production in jars containing *Hydrilla* compost was sparse, and the jars with *Spirodela* compost produced only about half that of jars containing *Eichhornia* compost. The plankton production was directly related to the nutrient content of the composts. Field trials on this promising method of utilizing water hyacinth should be conducted to assess fully its potential.

## BIOGAS SLURRY

Biogas digesters, using animal manure or human wastes mixed with vegetable matter, are common in China, Korea and India. Water hyacinth, however, can also be digested to produce methane without dewatering or the addition of animal or human wastes, since its carbon: nitrogen ratio is between 20 to 30:1. The weeds must be crushed or chopped before use. There is a lag period of up to 10 d before the oxygen, introduced into the digester with the weeds, is used up by aerobic bacteria. Biogas production takes 10 to 60 d and requires skill and supervision. Each kg dry weight of water hyacinth produces 370 ℓ of biogas (Ruskin and Shipley 1976).

The slurry or liquid sludge can be further used as an organic fertilizer, since only carbon has been lost during the biogas process. Perhaps the best way to utilize the slurry would be as an organic fertilizer in fish ponds rather than on crops, but research is required to investigate this. Experiments are being conducted at the village level in India to cultivate *Spirulina platensis* for animal feed on biogas slurry (Seshadri 1979).

# Aquatic Macrophytes as Food for Herbivorous Fish

Since there are several fish species that feed on aquatic macrophytes, it is worthwhile considering the feasibility of using such fish in integrated farming systems. The relationship between aquatic macrophytes and fish is complex, however, because the vegetation, besides providing a food source, also strongly influences the chemical and physical nature of the aquatic environment.

## HERBIVOROUS FISH SPECIES

There are many species of fish that are reported to feed on aquatic macrophytes (Swingle 1957; Hora and Pillay 1962; Blackburn et al. 1971), but species which are voracious feeders on vegetation need to be distinguished from those fish which are omnivorous and which would be less useful for the conversion of vegetation into fish tissue. A third group of species includes those for which feeding habits are imperfectly known, but which may have potential as consumers of aquatic macrophytes.

Perhaps the most promising species for the consumption of aquatic macrophytes is the grass carp or white amur, *Ctenopharyngodon idella* (Swingle 1957; Blackburn et al. 1971). There is a voluminous literature on this species, which may be one of the fastest growing species of fish. At Malacca, fingerlings stocked at 2 g grew to an average weight of 3.3 kg in 267 d and 4.2 kg in 413 d (Hickling 1960). The Kara Kum Canal in Russia had its planned flow rate so reduced by aquatic macrophytes that the loss was estimated at 20,000 ha of irrigated cotton fields, but there was a notable decrease in aquatic weeds after stocking grass carp; 375 fish, total weight 55 kg, cleared 22 mt of plants from 1.8 ha in 110 d (Hickling 1965). In 1970 it was estimated that 20,000 ha of public lakes in Arkansas were infested with submerged macrophytes, but 15 years after the introduction of grass carp, there were no infestations of problem magnitude remaining and the fish were being marketed (Ruskin and Shipley 1976).

The gut of the grass carp is unusually short for a herbivore and probably only 50% or less of consumed vegetation is utilized by the fish (Hickling 1971; Alabaster and Stott 1967). This knowledge is used in the polyculture of Chinese carps, of which grass carp is the central species (Ling 1967). The grass carp acts like a living manuring machine and its faeces lead to the production of natural food in the pond. The natural food is utilized by a judicious stocking of other fish species, the total crops of which can equal that of the grass carp itself (Hickling 1971). The plant food for the grass carp may consist of leaves and stems of terrestrial plants, e.g., grass, or aquatic macrophytes such as water spinach and duckweed (Ling 1967).

*Tilapia rendalli (T. melanopleura)* and *T. zillii* are also voracious feeders on certain plant species (Meschkat 1967; Semakula and Makoro 1967; Hickling 1971). These two species led to the total eradication of weeds after only 2.5 to 3 yr in reservoirs of 2 to 10 ha in Kenya, which were formerly choked with weeds (Van der Lingen 1968). Over 0.5 million *T. zillii* were stocked at 2,500 fish/ha in the weed filled canals of the Imperial Valley, S. California, in 1975 and completely eliminated submerged macrophytes (Ruskin and Shipley 1976). *T. zillii,* however, does feed also on phytoplankton, zooplankton, benthic animals and detritus (Spataru 1978).

*Puntius gonionotus* feeds on both filamentous algae and certain species of higher plants (Hora and Pillay 1962; Hickling 1971) and in Malacca was grown in polyculture with *Sarotherodon mossambicus* so that the latter species could consume the plankton which developed through the fertilization of the *Puntius* faeces (Hickling 1971). *Puntius* has been used successfully to control aquatic macrophytes in Indonesia. In 1926 dams were built in E. Java for irrigation water, but a few months after filling, a dense vegetation of *Ceratophyllum* and *Najas* developed which could not be removed manually because of the rapid growth of the weed. *Puntius* was stocked and 8 mo later 284 ha of reservoir were free of vegetation (Schuster 1952). Before 1937, Tempe Lakes in Indonesia, a group of shallow waters covering about 20,000 ha in the wet season, were infested with several species of aquatic macrophytes. *Puntius* was also stocked, most of the vegetaion vanished and in 1948 the annual yield of *Puntius* reached 14,000 t (Schuster 1952).

*Osphronemus gorami* is another fish that feeds mainly on plant leaves (Hora and Pillay 1962) and has been introduced into irrigation wells in India from Java to control submersed macrophytes (Philipose 1976).

There are other species of fish which feed at least to some extent on aquatic macrophytes, but it is unlikely that these species can be used as central species in aquatic macrophyte–herbivorous fish culture sytems. *Sarotherodon mossambicus* is reported to consume phytoplankton and certain species of aquatic macrophytes (Hora and Pillay 1962; Swingle 1957). Lahser (1967) reported, however, that although *S. mossambicus* is an efficient destroyer of vegetation, it has a preference for periphyton attached to larger aquatic macrophytes.

Observations of feeding in aquaria revealed that the consumption of many vascular plants is incidental to the removal of periphyton, which is scraped or rasped off the leaves, stems and roots. An examination of faeces showed that diatoms are used as food, but that most of the ingested filamentous algae and higher plant material pass relatively intact through the gut. *S. mossambicus* can control aquatic macrophytes under certain circumstances, although Avault et al. (1968) reported that the species failed to control higher plants. The occurence of filamentous green algae in brackish water milkfish ponds in Java is a problem since they are consumed by milkfish only when decaying and softened. *S. mossambicus*, however, consumes the algae and keeps the ponds weed free (Schuster 1952). *S. niloticus* will consume filamentous algae and some higher plants but much less efficiently than other tilapias (Avault et al. 1968).

*Trichogaster pectoralis*, sepat siam (Swingle 1957; Hora and Pillay 1962), *Carassius auratus*, goldfish (Swingle 1957; Avault et al. 1968), and the Indian major carps *Catla catla*, catla; *Labeo rohita*, rohu; and *Cirrhina mrigala*, mrigal (Hora and Pillay 1962) may feed to some extent on aquatic macrophytes.

*Cyprinus carpio* is often reported as being effective in aquatic macrophyte control, but it feeds mainly on benthic animals, decaying vegetation and detritus (Hora and Pillay 1962). Avault et al. (1968) demonstrated that it feeds on higher plants in aquaria, but only if little else is available. This is supported by the cultivation of two aquatic macrophytes, *Limnocharis flava* and *Ipomoea aquatica*, as vegetables for human consumption in the same ponds as *C. carpio* in Indonesia (Djajadiredja and Jangkaru 1978), which otherwise would not be feasible. The ability of *C. carpio* to control aquatic macrophytes is apparently due to its feeding habits, in which it disturbs the pond bottom, uproots aquatic plants and increases the turbidity of the water (Swingle 1957; Hora and Pillay 1962; Avault et al. 1968; Pruginin 1968).

The milkfish, *Chanos chanos*, feeds largely on a bottom complex of decayed green and blue green algae, diatoms, protozoa and detritus, but will feed on green algae and Characeae if these are softened by decay. Large fish will also consume large amounts of fresh filamentous algae and parts of higher plants (Hora and Pillay 1962). According to Villadolid and Bunag (1953), water hyacinth may be used as a supplementary food for milkfish. The weed is thrown onto the pond dikes for a week, after which it may be stored for future use, or piled immediately in the ponds. In 2 to 3 days, the piles rot and the milkfish feed on them voraciously. Alternatively, a pile of fresh weed is covered by a thin layer of mud in the pond, and when the pile rots in a few days, the fish will feed on the decaying weed.

The third group of species includes those that may have potential as grazers of aquatic macrophytes, but whose habits are not yet sufficiently known to be assessed adequately. Two fish from S. America known as silver dollar fish, *Metynnis roosevelti* and *Mylossoma argenteum* both consume submersed macrophytes (Yeo 1967; Blackburn et al. 1971; Anon. 1973; Ruskin and Shipley 1976). Dense growths of weed are rapidly removed at stocking densities of 1,200 to 2,500 fish/ha. Little is known of their potential yield or value as food, although they occur in large numbers and are sought and relished by people along the Amazon River (Ruskin and Shipley 1976). Their potential may be limited by their small size, since mature *Metynnis roosevelti* are only 7.50 to 8.75 cm long and *Mylossoma argenteum* only 8.75 to 10.00 cm long (Yeo 1967). Ruskin and Shipley (1976), however, report that they grow to a length of 13 cm. Two other Amazon fish, *Mylossoma bidens*, pirapitinga, and *Colossoma bidens*, tambaqui, are thought to have great potential in pond culture. Both are large fish which eat plankton, but also readily eat vegetation (Ruskin and Shipley 1976).

An estuarine species of *Tilapia, T. guineensis* from W. Africa, that can be kept in freshwater, may have potential since it feeds predominantly on terrestrial vegetation washed into estuarine areas (Ruskin and Shipley 1976).

Crayfish or freshwater lobsters may be a greatly underexploited food source. They are produced commercially in some European countries, and in the USA, and a few tribes in New Guinea use them extensively as their major protein source. There are more than 300 species and a few are exclusively herbivorous. *Procambarus clarkii*, red crayfish, is widely farmed in California and Louisiana in flooded rice fields and lives mainly on aquatic weeds that grow among the rice. The crayfish is too small to eat the rice seedlings at planting, and by the time the crayfish mature, the rice plants are too tall and fibrous to be eaten. Before crayfish are introduced into new areas, however, their effect on rice production should be studied carefully (Ruskin and Shipley 1976).

## FEEDING CHARACTERISTICS OF HERBIVOROUS FISH

To effectively utilize herbivorous fish to harvest aquatic macrophytes in either integrated aquatic macrophyte–herbivorous fish farming systems or for aquatic macrophyte control, it is necessary to understand their feeding habits and feeding efficiency.

Unfortunately, herbivorous fish do not eat all species of aquatic macrophytes with equal relish, but have distinct preferences. There have been several studies on the feasibility of using herbivorous fish, in particular grass carp, to control aquatic macrophytes because of the acute plant infestations in many water bodies in tropical countries. It is difficult to generalize, but certain broad preferences of grass carp feeding emerge. The most favoured plants are filamentous algae, soft submerged macrophytes and duckweed. Among the least favoured are rushes, sedges, water cress, water lettuce and water hyacinth (Singh et al. 1967; Alabaster and Stott 1967; Cross 1969; Bhatia 1970). It is unfortunate that the grass carp does not readily consume the water hyacinth, *Eichhornia crassipes.* Although it has been reported that grass carp will feed on water hyacinth (Blackburn and Sutton 1971; Baker et al. 1974), they apparently eat it when it is the only weed present (Avault 1965; Avault et al. 1968). Singh et al. (1967) observed that grass carp occasionally gulp in pieces of water hyacinth, but these are mostly disgorged immediately. There are also reports of grass carp losing weight when being fed only water hycinth (Singh et al. 1967; Baker et al. 1974). Although grass carp prefer more succulent plants, taste appears to be involved also (Alabaster and Stott 1967). Cross (1969) listed 16 plants eaten by grass carp in approximate order of preference and water cress, which is fairly succulent, was the 14th species listed.

Feeding of herbivorous fish is also influenced by environmental factors, such as temperature, pH, and fish stocking density (Hickling 1971; Alabaster and Stott 1967). According to Alabaster and Stott (1967), grass carp feeding becomes less selective and its intensity increases with an increase in temperature. The feeding of grass carp is also affected by the age of the fish (Mehta and Sharma 1972; Mehta et al. 1976), since the order of food preference by small fish (65 g) was different than for larger fish (200 g). The efficiency of feeding also decreases with age, since grass carp, approximately 10 times heavier, consumed only about 50% more vegetation than the smaller fish (Sutton 1974).

Herbivorous fish consume huge amounts of aquatic macrophytes. Bhatia (1970) reported that grass carp, weighing 1.00 to 1.25 kg consumed 100 to 174% of their body weight/d of certain aquatic macrophytes. Venkatesh and Shetty (1978) determined that grass carp ate 100% and 125% of their body weight/d of *Hydrilla* and *Ceratophyllum,* respectively.

To evaluate herbivorous fish for harvesting aquatic macrophytes, it is necessary to know the FCR (food conversion ratio). The most detailed study to date was conducted by Singh et al. (1967) in India, who determined the weight of different species of aquatic macrophytes consumed by grass carp over a given time period and the increase of weight of the fish. They did not calculate FCR's since they modestly considered their results to be tentative, but these can be calculated from their data. Although the data in the text do not always correspond to their tabulated data, about 20 FCR's can be calculated, involving about 8 species of aquatic macrophytes, either initially growing in ponds or added specifically for the fish to eat. If an unusually low FCR of 14 is discarded (for a duckweed pond, *Spirodela polyrrhiza*, which multiplied rapidly after its weight was determined and thus led to an underestimation of the weight of weed consumed) together with three unusually high values of 254, 499 and 971 (the FCR of 254 was for *Azolla pinnata* which started to die off naturally a few days after its weight was determined, and led to an overestimate of the weight of weed consumed), then the remaining 16 FCR's ranged from 23 to 158 with an average of about 58. Stott and Orr (1970) obtained an FCR of 280 with grass carp and lettuce. Michewicz et al. (1972a) obtained FCR's for grass carp feeding on duckweed in aquaria ranging from 21 to 81, with an average of 57, and with duckweed in outdoor concrete tanks, from 12 to 50, with an average of 29.

Food conversion ratios of 37 (Tal and Ziv 1978; Hepher and Pruginin 1979) and 10 (Tal and Ziv 1978) are reported from Israel in experiments feeding *Lemna* to grass carp; the latter figure is quite low and may be due to an underestimation of the weight of weed consumed. Sutton (1974) determined the efficiency of utilization of *Hydrilla* by grass carp and got an average FCR of 62 in static water concrete tanks and 389 in flowing water plastic pools. In the latter experiment, the *Hydrilla* was available at all times, and since some weed dropped to the pond bottom and decayed before it could be eaten, this could explain the unusually high FCR. Venkatesh and Shetty (1978) obtained FCR's for grass carp of 27 for the terrestrial napier grass, 94 for *Hydrilla* and 128 for *Ceratophyllum.*

The variation in FCR values reported in the literature is not surprising when it is realized that the feeding trials were conducted in containers varying in size from aquaria to large fish ponds, under varying environmental conditions, using aquatic macrophytes of several species, which themselves vary in water, nutrient content, and in palatability.

Since the FCR's are large, it is clear that the conversion of aquatic macrophytes into fish is a highly inefficient process. The single, largest factor that makes the process so inefficient is undoubtedly the large water content of aquatic macrophytes. This is supported by one of the few studies on the actual utilization of protein and cellulose in aquatic plants by a herbivorous fish. The utilization of the protein and crude fibre of *Spirodela polyrrhiza* (96.7% water, 0.6% protein and 1.03% crude fibre) by *Tilapia rendalli* were 42 to 55% and 52 to 68%, respectively and for *Elodea canadensis* (90.9% water, 2.1% protein, and 3.09% crude fibre) 43 to 57%, respectively (Mann 1967).

FISH YIELDS AND DENSE MACROPHYTE VEGETATION

Fish are attracted to beds of submersed and floating plants and in many parts of the Indian subcontinent, S.E. Asia, and China, this knowledge is used to capture wild fish (Anon. 1973; Ruskin and Shipley 1976; Hauck 1978); patches of water hyacinth and other floating plants are enclosed by bamboo stakes to attract fish, which are periodically encircled by a net and trapped (Fig. 15).

Excessive amounts of aquatic macrophytes, however, may lead to a considerable reduction in fish yields. In India, the productivity of fish ponds is considerably reduced by floating plants, especially *Eichhornia crassipes,* but also by submersed plants, such as *Hydrilla, Nechamandra, Ottelia, Ceratophyllum, Najas,* etc. (Bhimachar and Tripathi 1967). It has been estimated that 320,000 ha in India, 40% of the total cultivable waters for fish, have to be cleared annually (Philipose 1968). In Sri Lanka, some of the water bodies presently infested with *Salvinia molesta* were formerly good breeding grounds for fish, but now they are almost completely depleted (Kotalawala 1976). In Israel, ponds heavily infested with submersed weeds, such as *Potamogeton* sp., and *Ceratophyllum demersum,* yield only 600 to 700 kg/ha compared to 2,000 kg/ha following eradication of the weeds by the application of sodium arsenite. Similar results were obtained by removing the emergent macrophytes *Phragmites* and *Typha* (Pruginin 1968). In the U.S.A. a dense stand of *Potamogeton foliosus* in an Illinois pond reduced the surface area by 51.2% and the fish yield by 58.1% (Blackburn 1968). In 1931, fish production in Rawa Pening, a 2,500 ha reservoir in Central Java, was only 3.5 kg/ha/yr, but continuous efforts to reduce *Eichhornia crassipes* and the floating islands of aquatic macrophytes invaded by terrestrial plants, led to increases in fish production which reached 120 kg/ha/yr from 1950 to 1957 (Soerjani 1976).

Reduction in fish yields may occur because the macrophytes physically interfer with the actual fishing operation, as reported for the Nile Valley (Davies 1959).

Figure 15. Fish are attracted to artificially maintained beds of water hyacinth, *Eichhornia crassipes,* and are periodically netted, Thailand.

Figure 16. Setting a gill net in a pond completely covered by *Salvinia cuculata*, Thailand. Only air breathing fish such as catfish and snakehead thrive in such a pond.

In Thailand, the subsistence level fishermen often remove macrophytes manually from canals and borrow-pits before they attempt to net the fish. Dense growths of macrophytes also restrict fish movements and their living space, assimilate nutrients, which reduce the plankton production upon which several species depend, and, more seriously, may reduce the water quality due to adverse changes in dissolved gases (Pruginin 1968). A diurnal oxygen study in New Zealand revealed that the oxygen concentration in a dense bed of submersed macrophytes fell below that of the open water during the night due to heavy respiration and lack of water movement. Even during the day, at lower depths in the weed bed, the oxygen concentration was lower than in the open water at the same depth (Chapman et al. 1974).

Reductions in dissolved oxygen also occur beneath floating macrophytes and are likely to be more drastic if the vegetation cover is complete (Fig. 16). McVea and Boyd (1975) measured the dissolved oxygen beneath water hyacinth covering 0, 5, 10 and 25% of the pond surfaces. The concentration was adequate in all ponds for fish growth, but was lowest with the highest cover of vegetation. In Lake Kariba, Schelpe (1961) reported dissolved oxygen levels below *Salvinia* mats of 0.64 mg/ℓ near the surface and 0.66 mg/ℓ at depth of 1 m, compared to 4.4 mg/ℓ and 6.9 mg/ℓ in open water near the surface and at 1 m, respectively. Under thin, younger or disturbed mats the dissolved oxygen levels approached those of open water and thus the degree of deoxygenation was related to the thickness of the mats and the length of time for which the mat had not been disturbed. *Azolla pinnata* was introduced into S. Africa as an ornamental plant for fish ponds, but farmers reported that fish died in waters with the plant, the water developed a sulphurous odour and animals refused to drink it (Moore 1969). Ashton and Walmsley (1976) reported in S. Africa that the water beneath multi-layered mats of *Azolla filiculoides* was anaerobic and that the fish were unable to survive there.

Lewis and Bender (1961) studied the effects of duckweed on the dissolved oxygen and free $CO_2$ levels in ponds. They found that the dissolved oxygen was very low and the free $CO_2$ abnormally high in weed-covered ponds. They reported a fish kill in a pond completely covered with duckweeds, which had zero dissolved oxygen at all depths, and free $CO_2$ varying from 60 to 100 mg/ℓ. Krishnamoorthi (1976) also reported a dissolved oxygen level of almost zero and accumulation of $CO_2$ under a heavy growth of *Lemna.* Low concentrations of dissolved oxygen beneath floating macrophytes are caused by respiration of the pond biota and the oxidation of organic matter by bacteria, and are thus associated with increases in the concentration of free $CO_2$. If light were able to penetrate into the water, photosynthesis by phytoplankton would reverse the changes in dissolved oxygen and free $CO_2$. Since $CO_2$ reduced the affinity of the blood of many species of freshwater fish for oxygen (Alabaster et al. 1957) fish are asphyxiated at a higher concentration of dissolved oxygen when $CO_2$ is present than when $CO_2$ is absent.

It has been known for many years that phytoplankton blooms can have an adverse effect on water quality and lead to fish kills through the depletion of dissolved oxygen (Olson 1932; Smith and Swingle 1939). In sewage fed fish ponds in Calcutta, India, a margin of water hyacinth absorbs nutrients to reduce eutrophication of the pond water (Fig. 17).

Attempts have been made to use aquatic macrophytes to reduce the density of phytoplankton blooms that develop in the intensive culture of channel catfish, *Ictalurus punctatus,* in the U.S.A., due to fish excretory products and waste food. Water hyacinth was contained by barriers on a channel catfish pond and allowed to cover 10% of the pond area; it was found that the plant was able to remove enough nutrients to reduce the density of phytoplankton and thus decrease the probability of a fish kill (Boyd 1974). The Chinese water chestnut, *Eleocharis dulcis* has also been evaluated for its nutrient removal potential, since it is a valuable crop for human consumption, unlike water hyacinth (Loyacano and Grosvenor 1974; McCord and Loyacano 1978). Ponds with Chinese water chestnuts significantly lowered nitrate and ammonium levels but the extrapolated production was only 4,664 kg corms/ha compared to 52,768 kg corms/ha in field plots because they received nutrients only from fish excreta and waste food, and exhibited chlorosis, a symptom of nitrogen deficiency, late in the growing season. Heavy applications of fertilizer would be needed to get high yields, which would defeat the initial objective of growing the plants on the fish pond.

An interesting use of the duckweed *Lemna* has been reported from Bengal, where the plant is used to enhance

Figure 17. A margin of water hyacinth, *Eichhornia crassipes,* in a sewage fed fish pond to reduce dissolved oxygen fluctuations, India.

zooplankton production for carp nurseries. A phytoplankton bloom is created in small earthen ponds by adding organic manure and ammonium phosphate. *Lemna* is then added to form a uniform surface cover to destroy the algal bloom by reducing the light penetration into the pond. The *Lemna* is then removed and in the wake of the dying algal bloom, the zooplankton thrive (Alikunhi et al. 1952).

## Integrated Aquatic Macrophyte-Herbivorous Fish Systems

An ideal system would involve the growth of aquatic macrophytes and their harvest by herbivorous fish in the same water body. It would be difficult, however, to operate an integrated aquatic macrophyte-herbivorous fish system and obtain significant fish yields using submersed plants grown in the system. To provide an adquate supply of plant food for the fish, it would be necessary to fertilize the water to increase the macrophyte growth, but this would lead to the production of phytoplankton, which compete for nutrients and light. It appears that heavy growths of submersed macrophytes and phytoplankton are rarely compatible in the same system, mainly due to the shading effect of the phytoplankton which is particularly effective in eliminating macrophytes from the system (Hasler and Jones 1949; Vaas 1954; Swingle 1967; Lawrence 1968; Blackburn 1968; McNabb 1976). Indeed, the addition of fertilizers to fish ponds to stimulate filamentous, floating algae and phytoplankton and thus to eliminate submerged weeds, has been recommended in the U.S.A. (Lawrence 1968; Swingle 1967). This method must be used with caution, however, because of variable results and danger of overfertilization, which can result in dense phytoplankton blooms (Blackburn 1968). There is a report from Michigan where secondary sewage effluent was pumped to a series of artificial lakes and significant crops of the green alga *Cladophora fracta* and the submersed macrophyte *Elodea canadensis* were harvested, but this would appear to be an exceptional case (Bahr et al. 1977).

If floating macrophytes, such as duckweed, were used in an integrated aquatic macrophyte-herbivorous fish system, the addition of fertilizer would lead to the desired increase in growth of the macrophyte and competing phytoplankton would be reduced through shading. The same principle lies behind the proposal to use floating plants such as water hyacinth to eliminate phytoplankton from stabilization pond effluents in the U.S.A. to upgrade their quality (Dinges 1978). Duckweeds are often grown in small, well manured ponds for young grass carp, and if the pond is not too heavily stocked with fish, the growth of duckweed may keep pace with the rate of duckweed removal by the fish (Hickling 1971). Stanley (pers. comm.) also suggested an integrated duckweed-grass carp system. If an average productivity for duckweed is 22.1 t dry weight/ha/yr, its moisture content 92.5% (*vide* section on Recycling Wastes Into Aquatic Macrophytes) and an FCR of 43 is assumed (average of 5 FCR's calculated for duckweed from Singh et al. 1967), then the fish yield in such a system would be 6.9 t/ha/yr. If the cover of duckweed were complete, however, it could lead to anaerobic conditions in the water with a concomitant fish kill as described earlier. In fact, the fish yield would probably be considerably less than the calculated figure, since it is based on a high duckweed yield which would be associated with a substantial plant cover. The fish yield could be increased by stocking plankton feeding fish in addition to a macrophyte herbivore, to take advantage of the fertilization effect of the fish faeces, which could increase the yield by 50% (Hickling 1971). Thus, an integrated aquatic macrophyte-fish farming system may be feasible with floating vegetation but it does not appear to be generally feasible with submersed vegetation grown *in situ* in the same water body. Similar or greater yields could probably be attained in a manure driven system, with fewer management problems, by excluding aquatic macrophytes and by stocking mainly plankton feeding species of fish.

A system in which the aquatic macrophytes are cultivated in one water body and harvested for feeding to herbivorous fish reared in a second water body, would probably not be feasible due to the extra area required for the separate cultivation of vegetation and fish. Due to the low efficiency of conversion of plant material into fish tissue, a relatively large area would be required to grow enough macrophytes to obtain high fish yields. Furthermore, there would be additional costs for harvesting and transporting the plants. Unfortunately, the aquatic macrophytes which cause the most severe weed problems, such as water hyacinth, are not readily consumed by fish, which means that edible aquatic plants, such as duckweed, would have to be cultivated specially for fish feeding.

The grass carp is the central species in the raising of Chinese carps in polyculture, but is fed mainly terrestrial vegetation (Ling 1967). Venkatesh and Shetty (1978) determined the FCR of two aquatic macrophytes and the terrestrial hybrid napier grass fed to grass carp. They recommend a napier grass-grass carp integrated system since the FCR was 27 (for napier grass with 83% water content) compared to 94 for *Hydrilla* (with 90% water content) and 128 for *Ceratophyllum* (92% water content). Hickling (1960), however, reported a much higher FCR, about 48, for the conversion of napier grass into grass carp.

### AQUATIC MACROPHYTES IN IRRIGATION SYSTEMS

Since the distributary canals in irrigation systems are often shallow with slow moving and possibly nutrient rich water, they may suffer reduced water flow due to the prolific growth of aquatic macrophytes. In one Asian irrigation scheme, consisting of a 400 km main canal system, with distributaries totaling more than 1,600 km over an area of 560,000 ha, submersed vegetation cut the water flow in the main canal by 80% within 5 yr (Holm et al. 1969). Three years after commissioning the Chambal Irrigation System in India, submersed weeds spread over an area of 1,500 ha and reduced the carrying capacity of the canal by 50 to 60% (Mehta et al. 1976).

Herbivorous fish could be stocked in irrigation systems for aquatic macrophyte management, and, in addition, produce a fish harvest. In 1957, a 1,400 ha sugar cane plantation in Hawaii cut the cost of aquatic macrophyte control to virtually nothing by using tilapias. Vegetation was removed from the irrigation system using chemicals, and 75,000, 7.5 to 10 cm fry were released into the reservoirs and allowed to distribute themselves via the irrigation canals. The cost of the fish was US$3,000 compared to an annual cost of $ 5,000 for herbicides, but the cost of macrophyte clearance in two subsequent years was only $ 25 since the fish were able to keep regrowth at bay (Anon. 1973).

It is difficult to recommend appropriate rates of stocking (Alabaster and Stott 1967) since there may be several species of aquatic macrophytes present in varying amounts; the preference of the fish for various species varies (even within one fish species depending on the age of the fish), and there may be mortality of fish due to predators and losses to fields and drains (Mehta et al. 1976). Ideally the stocking rate should maintain an equilibrium between consumption and growth of macrophytes so that there is the least obstruction to flow and the fish have sufficient food throughout the year. Mehta et al. (1976) assumed that 100 grass carp of 1.0 to 1.5 kg body weight/ha would maintain such an equilibrium. Besides its voracious feeding, another advantage of using grass carp is that natural spawning in the tropics may be restricted due to the lack of stimulus of climatic change (Hickling 1967). This means that if adverse effects resulted from stocking the fish in an irrigation system, e.g., consumption of rice seedlings in flooded paddies, the problem would be shortlived, since the fish population would not be able to breed naturally.

Before herbivorous fish are stocked in an irrigation system to control unwanted aquatic macrophytes, studies should be made to ensure that the fish would not consume rice seedlings. Prowse (1969) reported that both *Tilapia zillii* and *T. melanopleura (T. rendalli)* will devour rice seedlings and should not be stocked in irrigation canals; but *T. zillii* is used on the Central Luzon State University model farm with integrated rice-fish culture and with no apparent ill effects to the rice (R.S.V. Pullin, pers. comm.).

# Other Aquatic and Amphibious Herbivores

The concept of harvesting aquatic macrophytes *in situ* may be extended to include other herbivorous animals.

## TURTLES

Yount and Crossman (1970) enclosed two Florida turtles, *Pseudemys floridana peninsularis,* in a tank with 23 kg of water hyacinth, some of which had been crushed, and the weed was almost all consumed within 6 d. Thus, there is a possibility of using edible, herbivorous turtles to harvest aquatic plants, which should be explored further. Their utilization may not be feasible, since several species of S. American herbivorous turtles are endangered species.

## RODENTS

The coypu or nutria, *Mycocaster coypus,* is a large amphibious rodent that reaches 8 kg in weight, and it feeds mainly on aquatic macrophytes. It is eaten in many parts of its native S. America and has been introduced into N. America, Europe and parts of Africa for its fur (Ruskin and Shipley 1976). It was also introduced into Israel to produce fur and meat and clear fish ponds of weeds. It was effective in controlling many aquatic weeds, but since the value of its fur is low and it needs to be fenced in, it is not economically profitable to raise it (Pruginin 1968). Another disadvantage is its burrowing activity, which can erode canal banks, so it should not be introduced into new areas without extensive prior ecological studies (Ruskin and Shipley 1976).

Capybara are large, amphibious rodents from Central and South America that feed on grasses and many species of aquatic macrophytes. During drought they will feed on water hyacinth. The S. American capybara, *Hydrochoerus hydrochoerus*, grows to 60 kg, the Panama capybara, *Hydrochoerus isthmius,* to about 30 kg. They are edible, but are not considered as a delicacy, although the natives of S. America eat them regularly. Research is underway in S. America on capybara husbandry. They should not be introduced into areas outside their native range, since they could become pests (Ruskin and Shipley 1976).

## MANATEES

Manatees, large mammals which can reach 0.5 t in weight, are voracious aquatic macrophyte feeders, and will even eat water hyacinth. There are three species, *Trichechus manatus* from the Caribbean and N.E. South America, *T. inunguis* from the Amazon and *T. senegelensis* from W. Africa. The main problem is that they are internationally regarded as endangered species and there are not enough animals left to remove them from the wild. They are slow growers and have never been bred in captivity. Almost nothing is known of their breeding habits and reproduction. They have the potential of being aquatic counterparts of beef cattle for the tropics, but hopes for the large scale utilization of manatees as a source of meat at our present stage of knowledge are unrealistic (Allsopp 1960, 1969; Ruskin and Shipley 1976).

# Health Hazards

The cultivation of aquatic macrophytes may cause health problems by providing habitats suitable for mosquito breeding or by contamination of the crop with human or animal wastes.

Aquatic vegetation enhances the production of mosquitoes by protecting the larvae from wave action, by providing a habitat for breeding (*Mansonia*), and by interfering with mosquito control procedures. The two major vectors are *Anopheles,* which transmits malaria, and *Mansonia,* which carries rural filariasis (elephantiasis) and encephalitis, although *Anopheles* and *Culex* have also been reported as vectors of filariasis (Oemijati 1973).

In Java, the occurrence of filamentous green algae in brackish water milkfish ponds led to the breeding of *Anopheles* mosquitoes and malaria problems, but the introduction of *Sarotherodon mossambicus* about 1940 kept the ponds free of filamentous algae (Hofstede and Bolke 1950; Schuster 1952). There are reports that heavy growths of *Azolla* (Burkill 1935; Moore 1969) and *Spirodela* (Culley and Epps 1973) prevent *Anopheles* mosquitoes from laying eggs in the water and prevent the larvae from coming to the surface for air. The common name of *Azolla* is "mosquito fern," probably due to attempts in the U.S.A. and Europe to use the plant to prevent mosquitoes from breeding in shallow water (Moore 1969).

The eggs of *Mansonia* are laid on the undersides of leaves of aquatic macrophytes just above the surface of the water. The mosquito larva inserts its respiratory siphon into the air-containing tissues of the plant and never surfaces; the pupae also have respiratory horns. The air is obtained from the submerged portions of the plant, especially from the roots (Wilcocks and Manson-Bahr 1972). Different *Mansonia* species have a preference for certain water plants but water lettuce *Pistia stratiotes,* seems to be the most common host, followed by water hyacinth and then *Azolla* and duckweeds (Foote and Cook 1959). Holm et al. (1969) described an experiment in which the destruction of 120 ha of water lettuce led to the complete control of *Mansonia* for 4 mo; only an occasional mosquito was trapped in the year following the treatment.

Filariasis has now spread all along the coastal belt and to the central highlands of Sri Lanka because of the spread of *Pistia* and *Salvinia,* which provide breeding grounds for *Mansonia* mosquitoes (Kotalawala 1976). However, in Indonesia where filariasis is endemic, a comparison of data from older investigations and recent surveys revealed a marked decrease in the percentages of the population in two areas infected with microfilaria. In 1960, Kresek, an extensive swampy area with abundant *Eichhornia crassipes* and other water plants, had a population with a microfilaria infection rate of 22%, with the mosquito vector *Mansonia indiana* common in houses. A re-investigation of the area in 1970 revealed that the swamps had been converted into rice fields by the construction of irrigation canals, the disappearance of *Eichhornia* and the mosquito vector, and a microfilaria infection rate of only 1%. A similar transformation took place in the Serayu delta, which formerly was a stagnant water area heavily infested with *Pistia stratiotes* (Oemijati 1973).

An effective way to prevent the breeding of mosquitoes in water containing aquatic macrophytes, is to stock fish that feed on mosquito larvae. Le Mare (1952) reported no undue breeding of mosquitoes in ponds used to cultivate *Ipomoea aquatica* since the ponds also contained *S. mossambicus,* the young of which are effective larval feeders.

The fertilization of aquatic macrophytes with faecal matter, or the cultivation of the plants in water that may be incidentally contaminated, may be a health hazard. Aquatic macrophytes are fertilized with human wastes and used as human vegetables in certain parts of Asia. Water spinach, *Ipomoea aquatica,* is fertilized with nightsoil in Hong Kong (Edie and Ho 1969). *Ipomoea aquatica* and *Neptunia oleracea* are both cultivated in canals and borrow-pits in Thailand which are contaminated with human faecal matter (Fig. 18). In Taiwan, human waste is used to fertilize duckweed, which is harvested to feed livestock and grass carp.

There are three types of health hazards associated with the faecal contamination of aquatic macrophytes (Feachem et al. 1978). First, there is an occupational risk to people who work in the water, especially where nightsoil is used as a fertilizer. The workers may accidentally swallow the pathogens or carry them home on their body or clothing, and may also become infected pericutaneously with schistosomiasis if the disease is endemic and the intermediate host snails are present in the water. The snails find shelter and food in aquatic macrophyte communities. Secondly, the harvested plants may be contaminated with pathogens and may infect people who handle, prepare, or eat them. Some plants may be eaten raw, e.g., water chestnut in China (Feachem et al. 1978), and *Ipomoea aquatica* and *Neptunea oleracea,* which are grown in faecally contaminated canals in Thailand. Thirdly, the metacercariae (infective stages) of certain trematodes may attach to the leaves, stems and fruits of certain aquatic plants. The metacercariae of the cattle liver fluke *Fasciola hepatica*

Figure 18. Harvesting water spinach, *Ipomoea aquatica,* as a vegetable in a faecally polluted borrow pit, Thailand.

usually attach to *Limnocharis flava* and *Ipomoea aquatica,* whilst the metacercariae of the intestinal fluke *Fasciolopsis buski* usually attach to *Trapa* spp., *Eliocharis dulcis* and *Zizania* spp. People become infected when they eat the encysted metacercariae on the raw water plants (Feachem et al. 1978; Oemijati 1979). Control of the faecal contamination of aquatic macrophytes is difficult, but health problems would be allieviated by some form of treatment of human and animal wastes prior to their use as fertilizers. At the very least, the plants should be well cooked prior to consumption.

## Summary and Research Recommendations

### AQUATIC MACROPHYTES AS HUMAN FOOD

More than 40 species of aquatic macrophytes are edible but several clearly have little potential since they are eaten only rarely, particularly during food shortages e.g., water lettuce, *Pistia stratiotes;* water hyacinth, *Eichhornia crassipes;* and the seeds of the water lillies, *Nymphaea stellata, N. lotus* and *N. nouchali.* Others may have specific environmental requirements which restrict their distribution, e.g., water cress, *Rorippa nasturtium-aquaticum,* which is confined to cool, flowing water. However, certain species clearly have potential for more widespread use, e.g., taro, *Colocasia esculenta;* Chinese water chestnut, *Eleocharis dulcis;* water spinach, *Ipomoea aquatica;* and *Neptunia oleracea.* Two plants with a high protein content, the blue green alga *Spirulina* and the duckweed, *Wolffia arrhiza,* warrant further study, but social acceptability may prove to be a greater constraint to their utilization than technical problems of cultivation.

Aquatic macrophytes may be cultivated in water-logged or swampy soils not suitable for either terrestrial crops or aquaculture and thus increase the area of productive land in a given area.

*Research recommendation 1:* a study of the protein content and yield of *Ipomoea aquatica* and *Neptunia oleracea* as a function of different concentrations of various organic fertilizers. The social acceptability of the plants will require study before attempts are made to introduce them into new areas. These two vegetables are easy to cultivate since they can be propagated from cuttings, and they grow year round in tropical areas.

### AQUATIC MACROPHYTES AS LIVESTOCK FODDER

Many species of aquatic macrophytes are used as livestock fodder, but, due to their high moisture content, animals cannot usually consume enough fresh plant matter to maintain their body weight. Aquatic macrophytes must be at least partially dehydrated to serve as fodder, but with many species there is also a palatability problem, which restricts the amount of material consumed. Animals usually cannot consume more than about 25% of their diet as aquatic macrophytes on a dry weight basis without losing weight, and sometimes much less. The production of dry feed from aquatic macrophytes is not economically feasible because the cost of harvesting, transporting and processing plant matter with such a high moisture content is too high relative to the quality of the feed produced. The utilization of aquatic macrophytes as fodder is probably feasible only on a small scale using simple methods of dehydration, e.g., sun drying. Small amounts of aquatic macrophytes may be used in livestock diets on a regular basis, but large amounts should only be used in times of conventional fodder shortages.

Silage can be made from aquatic macrophytes, but since its nutritive value is low, due in part to its high moisture content, it should only be used when other feed is scarce.

There are several recycling systems in existence in which livestock waste is used to fertilize aquatic macrophytes, e.g., water hyacinth, water spinach, duckweed and *Spirulina,* which are used as animal fodder. Duckweed may have the greatest potential because of its rapid growth rate, high crude protein content, apparent absence of a palatability problem, and floating life form which facilitates harvesting. Particular emphasis should be placed on *Spirodela* since there is evidence that duckweed yield increases with thallus size.

Aquatic macrophytes are used in Europe and the U.S.A. in the treatment of domestic and industrial wastes, but the possible contamination of the plants by pathogens and toxic chemicals may restrict their subsequent use as livestock fodder. The use of aquatic macrophytes to treat less dangerous agroindustrial wastes may be useful in Asia, since the plants could possibly be used as fodder.

*Research recommendation 2:* a study of the protein content and yield of the various types of duckweed in the tropics, as a function of different concentrations of various organic wastes. Most of the research to date has been carried out in subtropical and temperate regions of the U.S.A.

### AQUATIC MACROPHYTES AS FERTILIZER

Aquatic macrophytes are sometimes used as mulch and fertilizer, but the energy required to harvest, transport and spread them on land restricts such a practice to a small scale, adjacent to a source of aquatic plants. Allowing the plants to rot and using them as an organic fertilizer in fish ponds would probably produce a greater return than spreading them on land.

The production of ash from aquatic macrophytes for use as fertilizer is not economically feasible.

*Azolla* and certain species of filamentous blue green algae are used in some areas as biofertilizers to add nitrogen to rice paddies. Since the widespread use of biofertilizers could reduce the demand for inorganic fertilizers in developing countries, more effort is needed in this promising area of research.

Composting aquatic macrophytes may be the most promising method of utilization, since no mechanical devices or chemicals are required, little drying is needed, and transportation may not be necessary if the process is carried out close to the source of vegetation. The best way to use the compost may be as an organic fertilizer in fish ponds.

Aquatic macrophytes can be used in biogas digesters and the resulting slurry used as an organic fertilizer on vegetable crops, or better still as a fish pond fertilizer.

*Research recommendation 3:* a study of *Azolla* and filamentous blue green algae as biofertilizers.

*Research recommendation 4:* a study of composting aquatic macrophytes and the use of the compost as an organic fertilizer in fish ponds.

*Research recommendation 5:* a study of aquatic macrophytes in biogas production, and the use of the slurry as an organic fertilizer in fish ponds.

### AQUATIC HERBIVORES

There are certain species of fish which are voracious eaters of aquatic macrophytes, e.g., grass carp, *Tilapia rendalli, T. zillii* and *Puntius gonionotus,* but unfortunately many plants which are prolific in warm waters, e.g., water hyacinth, are not readily consumed by herbivorous fish.

The food conversion ratios of aquatic macrophytes into fish tissue are high. Fish yields may be increased by polyculture, in which other fish species feed on the natural food developed in the pond as a result of the fertilization effect of the herbivorous fish faeces.

An integrated aquatic macrophyte-herbivorous fish system is not feasible with submersed vegetation *in situ,* since fertilizer, added to stimulate growth of the vegetation, would also increase the production of phytoplankton and eliminate the submersed vegetation through shading. Such a system may be feasible with the floating duckweed, but there may be management problems in balancing the macrophytes and fish growth.

The use of herbivorous fish to control aquatic macrophytes in irrigation systems appears to be a promising technique.

The rearing of other herbivorous animals, e.g., turtles, amphibious rodents and manatees may not be feasible at present.

*Research recommendation 6:* a study of the feasibility of stocking herbivorous fish in irrigation systems with large aquatic macrophyte populations.

### HEALTH HAZARDS FROM THE CULTURE AND USE OF AQUATIC MACROPHYTES

The presence of aquatic macrophytes may lead to mosquito breeding, but *Pistia stratiotes*, the host plant for *Mansonia,* is unlikely to be cultivated since it has little value, and certain fish species can be stocked in the system to consume *Anopheles* larvae.

Contamination by pathogens through the use of animal and human waste as a fertilizer is more difficult to control. Ideally, wastes should be rendered inocuous by treatment prior to use as fertilizers.

The accumulation of toxic chemicals by aquatic macrophytes in waste recycling systems could be reduced by the separation of domestic wastes from industrial wastes.

## Acknowledgments

The author wishes to thank Mrs. Jirayoopin Chandraprasong for help with aquatic plant taxonomy, Drs. H. C. Bold and R. A. Stanley for responding promptly to requests for literature, Drs. C. Polprasert and W. Eppendorfer for valuable discussions, Mrs. Amara Sa-iam, Mrs. Nantha Thongkomvongs and Miss Chalaporn Suchiva for typing the manuscript, and Dr. R. S. V. Pullin for a critical review of the manuscript. The author is seconded by the Overseas Development Administration, London, to the Asian Institute of Technology, Bangkok.

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