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Food Potential of Aquatic Macrophytes

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ICLARM INTERNATIONAL CENTER FOR LIVING AQUATIC RESOURCES MANAGEMENT

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

Food Potential of Aquatic Macrophytes

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.

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March 1980
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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.

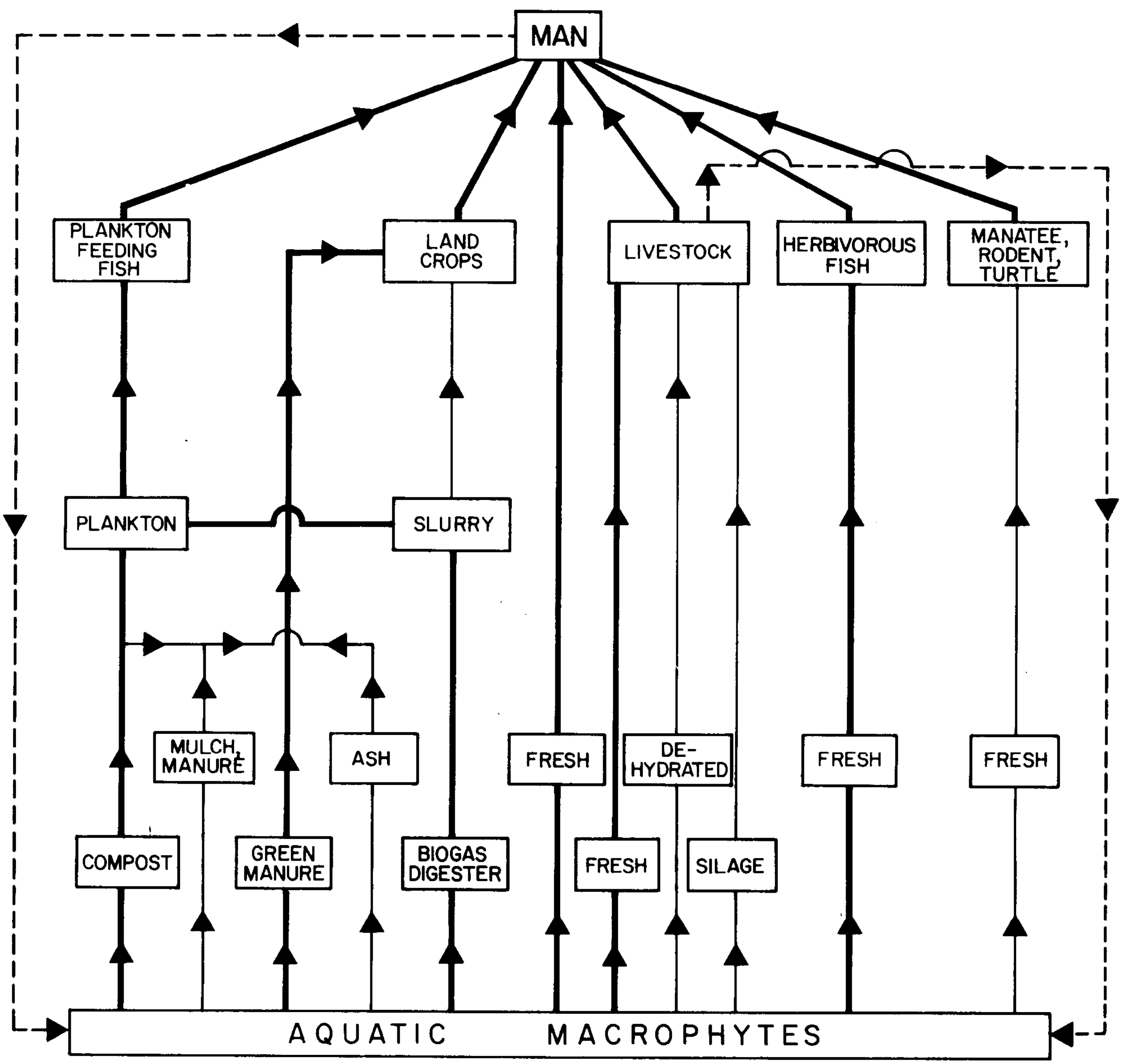

Figure 1. A scheme of the major pathways involving aquatic macrophytes in food production. Pathways which may have the greatest potential at present are in a heavier solid line. The dashed line indicates that the recycling of livestock and human wastes could play an important role in food production.

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).

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 fiddlerheads (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.