CHAPTER 20

Seaweeds

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I. INTRODUCTION

THE RESOURCE

This account is concerned with an overview of the seaweeds and seaweed resources of the tropical Pacific islands countries that are members of the Forum Fisheries Agency, namely: the Cook Islands, Federated States of Micronesia, Fiji, Kiribati, the Marshall Islands, Nauru, Niue, Palau, Papua New Guinea, Solomon Islands, Tonga, Tuvalu, Vanuatu and Western Samoa. Where appropriate, reference is also made to French Territories in the South Pacific region.

The seaweeds of this vast geographical region are not that well understood, and their potential as a resource has been scarcely developed. Tropical seaweeds have long been utilized by man as food, medicines, as ceremonial objects and for ornaments. Throughout the region, human consumption of seaweeds is widespread, although few detailed statistics are available on the quantities harvested. The value of these edible species may be considerable, as described by Abbott (1988a). There is significant potential for subsistence seaweed gatherers to cultivate edible seaweed species in tropical regions and nowhere is this less apparent than in the South Pacific.

The region's extensive coral reefs and lagoons characterized by slow to moderate currents, clear water, and sandy or coralline bottoms provide ideal habitats for seaweed farming (Littler and Littler, 1988; Adams and Foscarini, 1990; Ram, 1991). During the past 20 years the cultivation of *Eucheuma* (Rhodophyceae, Gigartinales) has become a significant activity in a number of Pacific islands countries. This development is part of a world-wide trend to cultivate seaweeds commercially for their valuable extracts (gums, or phycocolloids). The industry is concentrated in the Philippines, Malaysia, Indonesia, China and Japan although there is also a small industry based in East Africa (Mshigeni, 1984). *Eucheuma* is an ideal source of the phycocolloid carrageenan, which is a high-molecular-weight polymer polysaccharide comprised of simple sugars (Lewis *et al.*, 1988). According to Moss and Doty (1985: in Abbott, 1988a) the 1982 world production of carrageenan was 13,000 metric tonnes (mt); Neish (1990) quoted a production figure of 58,000 mt of kappa carrageenan-producing *Eucheuma* ("cottonii - type; see the section on Taxonomy below) and 7,600 mt of *E. spinosum* (iota-carrageenan) production for 1989. Both of these production levels fell considerably short of world demand. Eighty per cent of the world's production of carrageenan is now derived from aquaculture, principally in the Philippines.

CHARACTERISTICS OF SEAWEEDS

Seaweeds are Algae, members of the Plant Kingdom. Algae are a very diverse group of organisms which include both prokaryotic and eukaryotic forms (South and Whittick, 1987). There is considerable debate over the broader classification of the algae, but in recent treatments six algal Divisions (or Phyla) are recognized (Table I), incorporating some 16 different phyletic lines that can be assigned to the taxonomic rank of Class (Silva, 1982). The classes are principally distinguished on differences in pigmentation, storage products, cell wall characteristics, and the fine structure of organelles such as flagella, the nucleus, chloroplasts, pyrenoids and eyespots.

The algae are usually simply constructed, ranging from single-celled forms to aggregations of cells, filaments, or parenchymatous thalli. Even the most complex of forms show a low level of differentiation compared with most groups of plants. Their morphology is, however, very diverse (Bold and Wynne, 1985). Algae range in size from picoplankton as small as 0.2 - 2.0 µm in diameter, to giant kelps with fronds up to 60 m in length (Harlin and Darley, 1988). The seaweeds include those algae normally growing attached to the substratum in marine benthic habitats, and having a plant body readily visible to the naked eye (often referred to as the marine benthic macrophytes although this includes seagrasses). Seaweeds belong to four principal Classes (Table I), the Blue-green Algae (or Cyanophyceae), the Green Algae (Chlorophyceae), the Brown Algae (Phaeophyceae) and the Red Algae (Rhodophyceae). Other Classes of algae that include some macroscopic forms found in the marine environment are the Diatoms (Bacillariophyceae), the Yellow-Green Algae (Xanthophyceae - especially the genus *Vaucheria*), Golden-Brown Algae (Chrysophyceae), and the Cryptophytes (Cryptophyceae).

The algae demonstrate as much variation in reproduction as they do in morphology; reproduction may include vegetative, asexual and sexual processes, and in many algae an alternation of generations occurs. In the majority, motile zoospores or gametes are formed. Sexual reproduction in the Rhodophyceae may be the most complex in the plant kingdom (South and Whittick, 1987).

Seaweeds are autotrophic, photosynthetic plants and are important primary producers; in comparative terms, the productivity of an algal bed or reef is considerably higher than that of a tropical rain forest (1,167 compared with 988

Table I. The general classification of algae. Seaweeds are members of the Cyanophyceae, Rhodophyceae, Phaeophyceae and Chlorophyceae. Those classes marked * include some macroscopic forms occurring in the marine environment.

	Division	Class
Prokaryota	Cyanophyta	Cyanophyceae (Blue-green algae, or Cyanobacteria)
Eukaryota	Prochlorophyta	
	Rhodophyta	Rhodophyceae (Red Algae)
	Chromophyta (Golden-Brown Algae)	Chrysophyceae
		Prymnesiophyceae
		Xanthophyceae * (Yellow-Green Algae)
		Eustigmatophyceae
		Bacillariophyceae * (Diatoms)
		Dinophyceae
		Phaeophyceae (Brown Algae)
		Raphidophyceae
		Cryptophyceae (Cryptophytes)
	Euglenophyta	Euglenophyceae
	Chlorophyta	Chlorophyceae
		Charophyceae
		Prasinophyceae

$gC.m^{-2}.y^{-1}$; Harlin and Darley, 1988). They are a significant feature of most shorelines and shallow water environments throughout the world. They are an important food source for many grazing invertebrates and vertebrates, a source of shelter for many organisms and, when present in abundance, may substantially modify the environment to the benefit of many species. In addition, they may be an important or even a primary substratum for the attachment of other, smaller algae and sessile animals. The most abundant populations of seaweeds occur on hard substrata such as rock and corals, as well as man-made structures, and on the breathing roots of mangroves. They may also form extensive populations in sheltered, shallow water habitats growing in soft substrata or, sometimes they may grow unattached. In tropical environments, some Phaeophyceae (such as *Sargassum* and *Turbinaria*), may form prominent bands on the lower seashore, and the partially calcified blades of *Padina* species may be conspicuous in warm shallow lagoonal habitats. The diversity of the Phaeophyceae decreases significantly towards the tropics, however, and the Chlorophyceae and Rhodophyceae predominate in terms of number of species. Seaweeds, especially heavily calcified members of the Chlorophyceae and Rhodophyceae, are important, if not the predominant contributors to reefs. Many tropical algae are strongly adapted to heavily grazed environments and are often small and occupy cryptic habitats. Although they are not discussed here, it is also important to realize that microscopic, symbiotic algae are the essential partners of hermatypic corals and contribute significantly to the biomass of a coral reef (Round, 1981).

DISTRIBUTION AND DIVERSITY

Algae are ubiquitous, occurring in practically every well-lit habitable environment on earth. Seaweeds are found world-wide, from the polar regions to the tropics, and are prominent organisms in the shallow water, photic zone ranging from the spray zone well above high tide level, to depths as great as 268 m (Littler *et al.*, 1985).

The highest diversity of seaweed species occurs in the temperate regions of the world, especially Japan and southern Australia. Many tropical seaweed genera and species tend to be very widely distributed (pan-tropical), and investigators will find many similarities in seaweed floras of quite widely separated regions. A significant number of other genera and species, however, have a discontinuous distribution (Indo-Pacific and W. Atlantic, but not W. Africa; Lüning, 1990). The level of endemicity is not high in the tropical Indo-Pacific region, even for extremely isolated locations like Rapanui where no more than 14 per cent of the 170 species is endemic (Santelices and Abbott, 1987).

LIFE HISTORIES

The complex life histories and reproductive strategies of tropical seaweeds are generally poorly understood, and a great deal of further research is required. In the tropics, seasonal growth and reproductive phenomena occur, although not always as markedly in cooler regions. Tropical seaweeds are subjected to heavy grazing pressures, and many have developed survival strategies including short or alternating life histories, various forms of spatial escapes, structural defenses and chemical defenses (Littler and Littler, 1988).

II. TAXONOMY

The taxonomy of economically important seaweeds, with specific reference to Pacific and Caribbean species, was reviewed in Abbott and Norris (1985) and Abbott (1988b). The taxonomy of many tropical genera is notoriously difficult and remains a major stumbling block not only to seaweed specialists, but also to ecologists and resource biologists; for this reason seaweeds, which play an extremely important role in tropical ecosystems, have often been ignored or given inadequate treatment in accounts of these ecosystems. Reference should be made to Round (1981), Cribb (1983), Littler and Littler (1988) and Price and Scott (1992) for overviews of the importance of algae in tropical ecosystems.

The taxonomic problems are exacerbated when the identification of species in the most abundant and important of the tropical seaweed groups and genera is difficult even for the expert (e.g. the Cyanophyceae; members of the genera *Caulerpa* and *Halimeda* [Chlorophyceae]; *Padina* and *Sargassum* [Phaeophyceae]; a majority of the small filamentous, turf-forming Rhodophyceae, and the ubiquitous and important encrusting calcified Corallinales [Rhodophyceae]). The scope of the task facing seaweed taxonomists is evident from the detailed account of the marine algae of the Philippines (Silva *et al.*, 1987). The excellent account of the marine algae of Solomon Islands (Womersley and Bailey, 1969; 1970) lacks a parallel in any other country of the tropical South Pacific.

The taxonomic difficulties are a result of the fact that many of the grounds on which species are delimited are based on poorly understood morphological variation, because many seaweed morphologies are substantially modified by habitat and the same species may appear very different when growing in contrasting sites. The lack of a good, illustrated flora with keys to species is another hindrance; even a small color-illustrated guide such as that produced by Magruder and Hunt (1979) for Hawaii and Littler *et al.* (1989) for the Caribbean would be a great help. Drs Isabella Abbott (University of Hawai'i) and Bill Magruder (Bernice P. Bishop Museum, Honolulu) are in the process of completing an illustrated flora of the marine algae of the Hawaiian Islands (*pers. comm.*). The flora of the Hawaiian Islands has sufficient overlap with that of the tropical South Pacific that this book will be of immense value to workers in the tropical Pacific at large. Dr Chris Lobban (University of Guam) has painstakingly compiled an iconography and bibliography of algae occurring in Guam and Micronesia.

Accurate identification of seaweeds also depends on access to well-curated reference collections for comparative purposes. The majority of the earlier taxonomically important collections of South Pacific seaweeds are held in European herbaria; the majority of specimens on which recent lists are based (mostly stemming from the 1950s onwards) are housed in herbaria in North America (including Hawaii), New Zealand and Australia. There are reference collections of tropical Pacific seaweeds, housed in various regional institutions or in private collections, but there is presently no regional collection held in a recognized centre; priority should be given to the creation of such a regionally-based centre.

Potential seaweed resource surveys are hampered in that field identification of most tropical seaweeds is possible only for the larger, better-known species; the majority of species require microscopic examination in the laboratory for proper identification. Many of the Rhodophyceae cannot be accurately determined to the species level unless reproductive plants are found, and many of the filamentous species occurring abundantly in the algal turf in tropical habitats are often sterile. The conduct of on-the-spot field surveys requiring accurate naming of algal species is thus very difficult, even for the trained phycologist. Furthermore, there is no more than a handful of trained seaweed experts resident in the South Pacific islands at the present time (Guam: Dr R. Tsuda and Dr C.S. Lobban; New Caledonia: Dr C. Garrigue; Fiji: Dr G.R. South; Tahiti: Dr C. Payri).

Local names are used for seaweeds of economical importance (*i.e.* those grown for the extraction of commercial products, or those collected for human consumption); these names vary from country to country, but they are not well documented for the Pacific Islands (*cf.* Abbott, 1984). Abbott (1978; 1984) and Abbott and Williamson (1974) have extensively studied the ethnobotanical aspects of Hawaiian seaweeds. It would be valuable to have a comparable study made of the ethnobotany of seaweeds for the South Pacific island countries. Often, the local names refer to individual species, although there are exceptions. For example, *nama* (Fijian) refers to *Caulerpa racemosa*, a species commonly consumed fresh, and sold in Fijian markets, whereas *lumi* (*lumi* in Fiji; *limu* in Hawaii), refers to one or more species of *Hypnea* and *Gracilaria* (Rhodophyceae) and *sagati* to several species of *Codium* (Chlorophyceae), all consumed by Fijians (Prakash, 1990). Because of the growing interest in mariculture and the gathering of seaweeds for human consumption, an attempt has been made to standardize the names of sea vegetables and their products (see Chapman and Chapman, 1980).

The red seaweed *Eucheuma*, a commonly cultivated species, has a variety of local names. The Malay word "*agar-agar*" refers to *Eucheuma* species, although it is now known that *Eucheuma* yield carrageenan, not agar. To add to the confusion, the "trade names" used by the industry are different from the commonly accepted scientific names (Abbott, 1985).

The taxonomy of *Eucheuma* has been reviewed by Doty (1985) and Doty and Norris (1985). Doty (1985) described *E. alvarezii*, which is the principal kappa carrageenan producing species, and the most widely cultivated (the "cottonii" type of the industry), and of which there are three varieties:

E. alvarezii var *alvarezii* Doty
E. alvarezii var *tambalang* Doty
E. alvarezii var *ajak-assi* Doty

Doty and Norris (1985) provide a key to the species and species groups of *Eucheuma*, in recognition of the considerable confusion and inconsistency in the use and naming of the different species by taxonomists and the business world. Essentially, only the following four species are utilized commercially: *E. alvarezii; E. gelatinae; E. denticulatum; and E. striatum.*

Eucheuma alvarezii and *E. striatum* are kappa carrageenan producers; the other two are iota carrageenan producers. The kappa-producing species are now included under the genus *Kappaphycus* Doty.

III. GEOGRAPHICAL DISTRIBUTION

The overall geographical distribution, biogeography and evolution of seaweeds world-wide is described in the excellent compendium of Lüning (1990). Worldwide, the number of seaweed species (Chlorophyceae, Phaeophyceae and Rhodophyceae) is approximately 8,000 (Lüning, 1990); new taxa are continuously being described. The total number of seaweed species that occurs in the tropical South Pacific is not known, because relatively few geographical regions have been thoroughly studied and many locations have never been visited by a seaweed expert. The 550 species recorded for Micronesia (Tsuda and Wray, 1978; Tsuda, 1981) is probably the best existing estimate of diversity for a large South Pacific tropical region. Extensive floristic studies of some regions have been made (*e.g.* Solomon Islands: Womersley and Bailey, 1969, 1970) and there are a number of important monongraphic studies of selected groups of seaweeds occurring in the region (*e.g.* Hollenberg, 1967; 1968a, 1968b, 1968c for Rhodomelaceae [Rhodophycea], including *Polysiphonia* and *Herposiphonia*; Yamada, 1926 *et seq.* for various Chlorophyceae; Hillis, 1959 and Hillis-Colinvaux, 1980 for *Halimeda* [Chlorophyceae]; Ducker, 1967 for *Chlorodesmis* [Chlorophyceae]; Valet, 1968 [for Chlorophyceae]; Valet, 1969 [Dasyoladales]). There is currently no overview or flora of the South Pacific region comparable, for example, with that of Taylor (1960) for the tropical and sub-tropical Americas.

The large majority of the South Pacific islands seaweed species are immigrants and are widely distributed (Lüning, 1990). Early exploration and description of the seaweeds of the tropical South Pacific region were based on collections made during various expeditions in the mid- to late 1800s, whereas modern treatments stem largely from the 1950s onwards. Tsuda and Wray (1977) and Tsuda (1981) provide an authoritative and comprehensive summary of the 550 species that are known from Micronesia (including a geographical break-down). For Melanesia, the modern species compilations are available for New Caledonia (about 350 species; Garrigue and Tsuda, 1988), Fiji (about 310 species; South and Kasahara, 1992) and Solomon Islands (233 species; Womersley and Bailey, 1970). Three hundred and fifty species (111 of which are Cyanophyceae) have been recorded for French Polynesia (*cf.* Payri and Meinesz, 1985; Payri, 1991), and 170 for Easter Island (Rapanui) (Santelices and Abbott, 1987). Chapman (1977) and MacRaild (1978) reviewed the algae of the Cook Islands and Fiji, and South and Yen (1992) have made a preliminary report on the reef-inhabiting algae of Nauru. Knowledge of the seaweeds of Tonga and Samoa is largely based on very old reports (*e.g.* Grunow, 1874), and there appears to be little published on the flora of Vanuatu (previously known as the New Hebrides), Niue, the Tokelau Islands or Papua New Guinea (see Lüning, 1990). Attempts to compare seaweed diversity between regions of the tropical South Pacific are currently hampered by this lack of a comprehensive range of published flora and species lists, although Payri (1991) has suggested that, based on existing published lists, there is a decrease in diversity from the western to eastern South Pacific. In general terms, the flora of high islands are more diverse that those of atolls.

Marine algal resources in the Asia-Pacific region were discussed in Furtado and Wereko-Brobby (1987), and general accounts of commercially important seaweeds in the South Pacific region were published in Adams and Foscarini (1990), reporting on the results of a regional workshop on seaweed culture and marketing. Most of the seaweed harvested for human consumption in Pacific islands artisanal and subsistence fisheries are widespread throughout the region (*e.g.* species of *Caulerpa* and *Codium* [Chlorophyceae]; *Gracilaria* [Rhodophyceae]; *Codium* [Chlorophyceae]) although there is little mention of them in the literature (Abbott, 1988a; Prakash, 1990) and no regional account of these species has been prepared.

The only significant commercially important seaweed resource in the South Pacific islands is the red seaweed *Eucheuma*, although as has been pointed out, all of the culture stock originates from outside the region. The industry has its origins in the Philippines and is still relatively new and untested throughout most of the region (McHugh and Philipson, 1989; Adams and Foscarini, 1990; Ram, 1991). Naturally occurring species of *Eucheuma* are currently not used in commercial production in the region, and to date no attempts have been made to grow edible species, or other valuable resource species, on a commercial basis.

IV. *EUCHEUMA* AQUACULTURE IN THE SOUTH PACIFIC

More than 50 Rhodophyceae of the Order Gigartinales are known sources of carrageenan (Moss and Doty, 1987), and the tropical genus *Eucheuma* (Gigartinales, family Solieriaceae) is one of the most important, accounting for 80 per cent of the world supply (Neish, 1990). Accounts of *Eucheuma* and its cultivation are given by Doty (1973; 1979, 1986), Doty and Alvarez (1975), Doty and Norris (1985), Doty and Santos (1978), Parker (1974), Chapman and Chapman (1980), Laite and Ricohermoso (1981), Abbott (1988a), Abbott and Cheney (1982), Lewis *et al.* (1988) and Adams and Foscarini (1990), among others. The current industry has its origins in the Philippines, and Trono (1990) has provided an historical account of the Philippine industry. Nelson (1988) has described the development of phycocolloid-related industries in Oceania, and Gordon-Mills (1986) reported on prospects for marine phycocolloids in the Asia-Pacific region. *Eucheuma* farming in Fiji is described in Luxton *et al.* (1987) and Ram (1991), and Fijian farming techniques are detailed in Foscarini and Prakash (1990). Processing and marketing of *Eucheuma* are described in McHugh and Philipson (1989), and several accounts of the present status and prospects for the industry in the Pacific islands are given in Adams and Foscarini (1990).

ORIGINS OF THE CARRAGEENAN INDUSTRY

In Europe and North America the algae *Chondrus crispus* and *Gigartina stellata* (Rhodophyceae, Gigartinales) have been used for centuries in the making of jellies and puddings (Lewis *et al.*, 1988). The name 'carrageenin' was coined by Stanford (1862: in Lewis *et al.*, 1988) for the gelatinous water-soluble substance obtained from *Chondrus crispus*. The -an ending has been adopted in agreement with the -an suffix for the names of polysaccharides (Lewis *et al.*, 1988). The modern carrageenan industry dates from the 1940s, when it was discovered by the dairy industry that it is the ideal stabilizing substance for the suspension of cocoa in chocolate milk.

Until fairly recently there were two principal companies manufacturing carrageenans: the Marine Colloids Division of the FMC Corporation (USA) and the Copenhagen Pectin Factory (Denmark); these manufacturers, until the 1960s, relied on raw materials (hand-gathered *Chondrus* and *Gigartina*) through a cottage industry style system. Currently other manufacturers are involved in purchase and processing of seaweeds for carrageenan, to a total of 80,000 mt of product annually (Neish, 1990).

In Asia and the Far East, algae of the genus *Eucheuma* have long been used as food, and in trades such as book binding (Lewis *et al.*, 1988). It was not until the 1950s, when *Eucheuma* was recognized as a valuable carrageenophyte by the western carrageenan industry, that the present large-scale cultivation and export of *Eucheuma* became established (Lewis *et al.*, 1988; Trono, 1990).

THE CARRAGEENAN INDUSTRY IN THE SOUTH PACIFIC

Farming of *Eucheuma* is favoured in the Pacific islands, partly because it requires a low level of technology and investment and is operable as a family activity, but also because it has little environmental impact and is normally compatible with traditional fishing and other subsistence uses of the inshore marine environment. In some countries, such as Fiji, it is now seen by government as a potentially important source of income and employment in the rural areas (Ram, 1991). Following are brief summaries of *Eucheuma* farming in the Pacific islands countries.

All South Pacific island's attempts to cultivate *Eucheuma* stem from development in the Philippines. The Philippine *Eucheuma* cultivation industry was first established in the late 1960s, and products from this industry have since become one of the most important fishery exports of that country (Trono, 1990). Unlike the Philippines, and for reasons discussed below, the Pacific islands have experienced great difficulties in their attempts to cultivate successfully *Eucheuma* in commercial quantities. Trials or actual cultivation of *Eucheuma* have been conducted in Fiji, Tonga, Kiribati, Solomon Islands, the Federated States of Micronesia and Tuvalu, and of these countries, only Fiji and Kiribati have had any reasonable success. The first (unsuccessful) trials, using Philippine seed stock, were in Fiji in the 1970s (Prakash, 1990). In 1977 the first trials were held at Christmas Island, Kiribati (Uan, 1990), using Hawaiian seed stock originally derived from the Philippines. Trials were commenced in Tonga in 1982 (Fa'anunu, 1990), and a new programme was established in Fiji in 1984 (Prakash, 1990), using seedstock from Tonga.

Fiji: (Luxton *et al.*, 1988; Prakash, 1990; Prakash and Foscarini, 1990; Robertson, 1990; Ram, 1991).

The first trial introduction of *Eucheuma* to Fiji was in the mid-1970s, when *E. alvarezii* var *tambalang* was imported from the Philippines and maintained for two years at Telau Island, near Suva (Viti Levu). A feasibility study was later conducted, with seedstock from Tonga, by the Fiji Fisheries Division and Coast Biologicals Ltd., a New Zealand company, with funding support from the Commonwealth Fund for Technical Cooperation (CFTC). These trials were conducted at Tavua, Rakiraki and Tailevu (Viti Levu).

Successful trials from 1984 to 1986 led to the first commercial production in 1986, at Tavua, Rakiraki and the Kuba/Kiuva/Rewa area. Many farms were established, and by the end of 1986 there were 160 farms, with a production of 200 mt. Considerable expansion took place in 1987, by which time there were 240 farms producing a total of 217 mt for export.

There were substantial set-backs in 1987-1988, however. The political situation in Fiji and the effects of Cyclone Bola, which destroyed about 50 per cent of the crop, led to a near-collapse of the industry and the pull-out of Coast Biologicals.

Since 1988 the industry has seen a revival, through the efforts of the FAO South Pacific Aquaculture Development Project and the Fiji Fisheries Division, and with financial support from the New Zealand government. Marketing assistance has been through the Fiji National Marketing Authority and the FMC Corporation, Marine Colloids Division. From the beginning of 1990, marketing was carried out by a joint-venture company, Seaweed (South Pacific), with 30 per cent private shares and the remainder of the funds coming from Australia, New Zealand and the United States. The company set up a farm at Nanuca, Savusavu (Vanua Levu) in 1989, employing 40 Fijian farmers and establishing a commercially viable farming protocol. Unfortunately, Seaweeds (South Pacific) withdrew after only a short time, and the Fiji Fisheries Division sought the assistance of the National Marketing Authority to take over the marketing of seaweeds. A summary of Fiji *Eucheuma* production for 1985 - 1989 is shown in Table II. Currently, production is centered on three areas: Kiuva, Savusavu, and Moturiki.

It is evident that *Eucheuma* farming is technically feasible and economically worthwhile in Fiji. Set-backs to the industry have been due to marketing difficulties, the effects of weather (cyclones), and to recent political and economic instabilities.

Kiribati: (Why, 1987; Uan, 1990).

Eucheuma was first introduced into Kiribati in 1977, from Hawaii, and numerous trials were carried out with both *E. alvarezii* and *E. spinosum*. Of the two, *E. alvarezii* was found to grow best in Kiribati, and in 1986 full scale commercial production of this species began. Six sites in the Gilberts have proved to be suitable: Beru, Aranuka, Abemama, South Tarawa, Abaiang and Butaritari, although growth monitoring studies are continuing at other sites. The Kiribati Fisheries Division has been actively promoting the industry and provides assistance to farmers, especially those in the outer islands.

Since 1985 a total of 525 mt of *Eucheuma* has been produced in Kiribati (Table II), and it was anticipated that over 200 mt would be produced by the end of 1989. There is considerable variability in the success of the various farms, and several important limiting factors have been identified, including the effects of algal epiphytes, and the occurrence of "ice-ice" (a whitening of the thalli at the points of branching, causing a disintegration of the plant). The siting of farms is important, because unpredictable westerly winds have occasionally destroyed up to 90 per cent of the crop at some localities. There have also been difficulties in finding reliable buyers and with human interference (such as from traditional fishing activities). Finally, although 500 farmers were involved in 1990, the farms are very small with little output, so there is a low incentive for them to become involved in *Eucheuma* farming full-time.

Solomon Islands: (Smith, 1990)

Trial *Eucheuma* farming did not commence in Solomon Islands until 1987 when, with technical assistance from the United Kingdom's Overseas Development Adminstration (ODA), a seaweed farming project was initiated by the Fisheries Division, Solomon Islands Government. The seedstock of *E. alvarezii* was obtained from Fiji.

As a result of various surveys, the most promising area for farming was found to be the Vonavona Lagoon (lying between Munda and Gizo in the Western Division). Farming is now concentrated at Rarumana, and trials are still continuing in several new areas. Production levels are low, and it has been difficult to accumulate sufficient quantities for commercial sales.

Difficulties experienced in Solomon Islands include grazing by siganid fishes, and the tendency by farmers to keep their farms small, with few operating at the recommended 300-line size. In addition, there has so far been little interest on the part of seaweed buyers.

Tonga: (Fa'anunu, 1990)

Seaweed farming trials in Tonga commenced in 1981 and, as in Fiji, involved Coast Biological Ltd., and funding assistance from the Commonwealth Fund for Technical Cooperation. As a result of trails, six areas in the Vava'u Group showed potential. In 1982 trails with both *E. alvarezii* and "*E. cottonii*" seedstock from Kiribati were commenced. From 1983 to 1984, six farms operated on a fully commercial basis. In 1984, a joint-venture between the Tonga Government and Coast Biologicals was established to coordinate shipping and marketing. By 1985-1986 there were 36 farms in operation, but in the following years the numbers of farms declined. Reasons for this were heavy grazing by rabbit fish, and problems in marketing. The targets set by the government and Coast Biological were not attained. Rabbit fish grazing resulted in closing down most of the Vava'u farms.

In 1986 further trails were carried out, this time in Fanga'uta Lagoon, Tongatapu. Growth was initially good, but heavy rains that year resulted in the total loss of the stock. Some farmers in Vava'u continued to struggle through that year, although with little or no profit.

Since the failures experienced resulted in the cessation of farming, the Tonga Fisheries Division has continued to maintain a seaweed plot, with the intention of initiating further trials in the future. In identifying constraints to *Eucheuma* farming in Tonga, the farmers noted rabbit fish grazing as the principal problem, followed by insufficient supplies of seedstock, unstable income because of the market, and biological and environmental problems (fouling, disease, bad weather, low water temperatures).

Tuvalu: (Gentle, 1990).

A preliminary smallscale trial has been carried out in Funafuti Lagoon, with assistance from the FAO, and using *'E. cottonii'* seedstock obtained from Kiribati. Poor weather conditions resulted in the loss of the stock; the experiment was therefore abandoned. There have been subsequent attempts to farm *Eucheuma* in Tuvalu, and the Tuvalu Fisheries Division intends to reestablish a pilot project in the future.

Federated States of Micronesia: According to McHugh and Philipson (1989) steps are currently being taken to expand commercial *Eucheuma* growing programme in Pohnpei State, with possible expansion to the states of Yap and Kosrae.

Table II. Commercial production (mt) of *Eucheuma* for three Pacific islands countries, 1983-1990.

	1983	1984	1985	1986	1987	1988	1989	1990	TOTAL
Fiji[a]	-	-	30.0	173.4	217.0	60.3	80.3	87.4	648.4
Kiribati[b]	-	-	26.4	65.0	31.8	42.0	159.4	200.0	524.6
Tonga[c]	3.0	11.0	5.0	2.0	1.5	-	-	-	22.5
Annual Totals	3.0	11.0	61.4	240.4	250.3	82.3	239.7	287.4	
GRAND TOTAL									1,175.5

[a] Fiji Fisheries Division Annual Reports.
[b] Uan (1990). The 1990 total is an estimate.
[c] Fa'anunu (1990). Since 1988 approximately 1 mt has been produced annually at the Tonga Fisheries Division seaweed plot.

FARMING TECHNOLOGY

Methods of farming *Eucheuma* have been well documented (*cf.* Doty, 1986), and the industry provides detailed information on methods and costs to potential growers (McHugh and Philipson, 1989). Prakash and Foscarini (1990) have produced an excellent booklet describing farming methods for Fijians (English and Fijian versions). Blakemore (1990) has provided an excellent account of post-harvest treatment and quality control. *Eucheuma* is a large, rapidly growing seaweed that, under farming conditions, is easily propagated vegetatively (sexual reproduction is rare in farm conditions); in suitable conditions crops can be harvested every 6-12 weeks. There are various color varieties of *Eucheuma* species, the most common being greenish and brownish.

The optimal conditions for successful growth of *Eucheuma* are (*cf.* Prakash and Foscarini, 1990):

- Water temperature ranging from 25 °C to 30 °C
- Salinity at 28 ppt or more
- A white sandy bottom with a limited amount of natural seaweed
- Moderate water movement, and an exchange with ocean water
- Clear water with good light penetration
- at least 0.5 m depth water at spring tide
- Absence of pollution
- Absence of fish grazing

Earlier methods of cultivating *Eucheuma* included the placement of fragments in coral crevices or by the use of nets (Trono, 1990). There are three principal farming methods now employed in the South Pacific: off-bottom (fixed monofilament lines between posts driven into the substratum), floating rafts, or floating long lines (Prakash and Foscarini, 1990).

Off-bottom method (see Fig. 1): Wooden stakes are driven into the substratum at 20 - 25 cm intervals, in straight rows, with the rows oriented parallel with the prevailing currents. The stakes are 5 to 10 cm in diameter, and up to 1.5 m long. Propylene lines (3 mm diameter) 5 m long are stretched between two stakes, and to each of these 30 pieces of raffia (tie-ties) are attached. The line preparation is usually done on-shore. The lines are suspended at least 20-30 cm from the sea bottom, and 20-30 cm below the level of the water surface at spring tide, so that the seaweeds are never exposed directly to the air or sunlight. Attachment of the seed stock is easily achieved from a small boat once the lines are in position. An ideal farm size that can be operated by a single person is in the range of 320 - 480 lines, although much larger farms can be managed providing there is sufficient labour available and the farm is properly managed.

Floating raft method (see Fig. 2): The floating raft method allows the seaweed to rise and fall with the tide, keeping it in more or less constant environmental conditions. The seaweed must be kept 20 to 30 cm below the water surface at all times. Frames of various sizes (*e.g.* 2.5 m square) are constructed from bamboo, mangrove or other buoyant and seawater-resistant materials. Monofilament lines (3mm diameter) are stretched across the frame 10 to 15 cm apart; 15 pieces of seaweed can then be attached to each line. The frames can be seeded on shore, the raft then taken to the growing site. The rafts

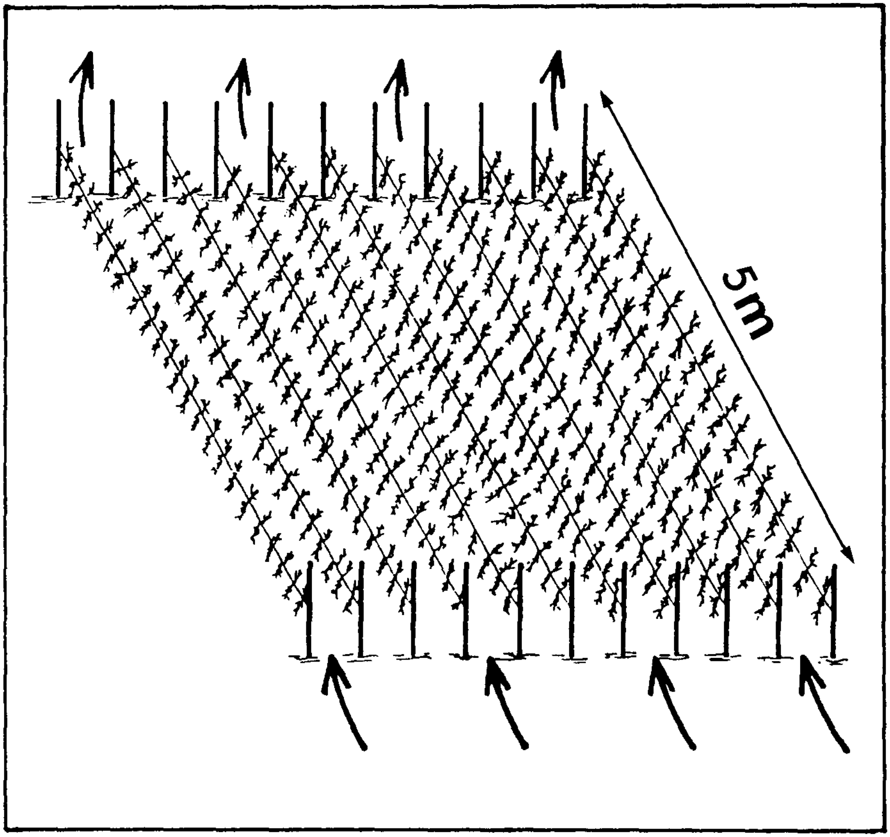

Figure 1. Diagram illustrating the off-bottom method of cultivating *Eucheuma*. Arrows indicate the preferred current direction in relation to the orientation of the lines. Modified from Prakash & Foscarini (1990), with permission.

should be securely anchored and, as the seaweeds grow and become heavier, bamboo floaters are required.

Longline method (see Fig. 3): The longline method is comparable to the floating raft method, but in this method the lines are stretched between floats, with anchors at either end. Seaweed should be attached to the lines after the lines have been stretched (to prevent tangling). The longline method is suitable for *Eucheuma* cultivation outside the reef.

Adams and Foscarini (1990) have described the advantages and disadvantages of the three methods. The off-bottom method is most suitable for pro-

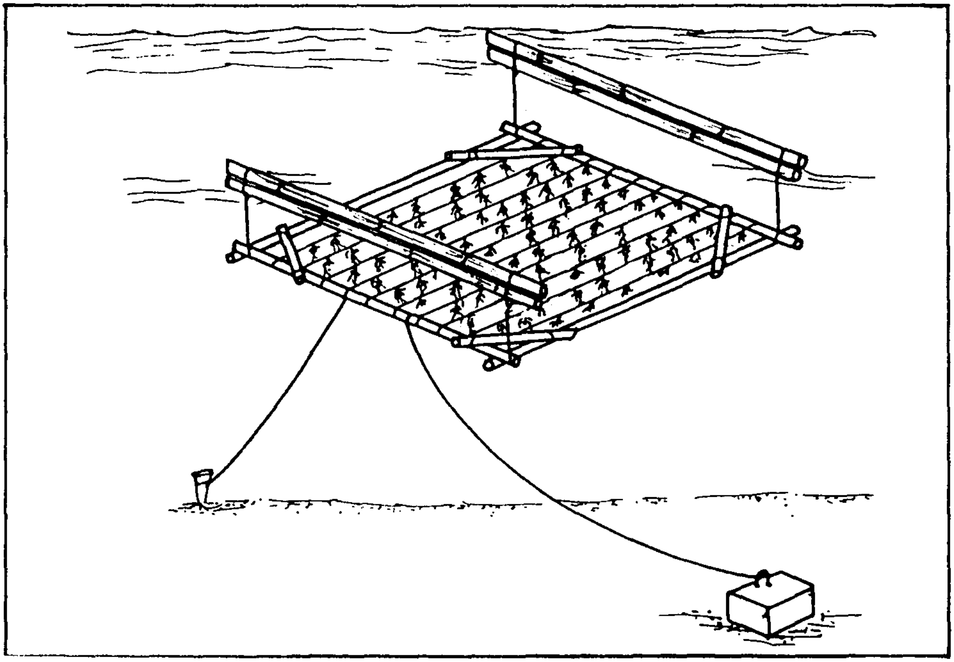

Figure 2. Diagram illustrating the floating raft method of cultivating *Eucheuma*. From Prakash & Foscarini (1990), with permission.

tected, shallow water sites with good movement and a lack of grazers, and it requires clean water with little siltation. The floating raft method requires protection from heavy waves and needs good anchorage. It is more suitable for sites with poor water movement and can be used in deeper water. An advantage is that it avoids space usage conflicts with tourism and other fisheries. The longline method can be used in exposed areas and where the water is over 30 m deep (*e.g.* outside fringing reefs). Problems may be experienced with stinging hydroids wrapping themselves around the lines in some seasons.

Harvesting: In Fiji, *Eucheuma* grows most rapidly in the cooler months. For the first 30 days growth is rather slow, but weight doubles about every 14 days thereafter. From an initial planting of 5 kg seedstock (30 pieces) a weight of 30 to 40 kg could be attained in 8-10 weeks (Fig. 4; Prakash, 1990).

At harvest, the plants are either removed from the lines, or simply pruned back heavily, leaving some of the stock attached for re-growth. In the first method, healthy young parts of the plants are retained as new seedstock, thus ensuring that the new crop is grown from fresh material. This method ensures the highest carrageenan content and gel strength of the extracted product. In

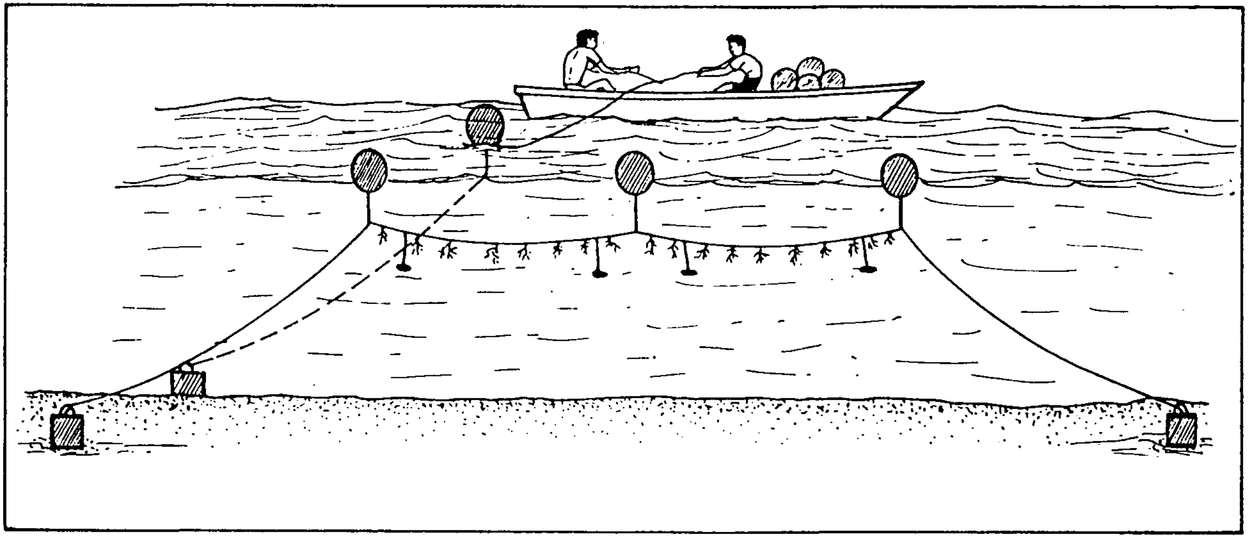

Figure 3. Diagram illustrating the longline method of cultivating *Eucheuma*. From Prakash & Foscarini (1990), with permission.

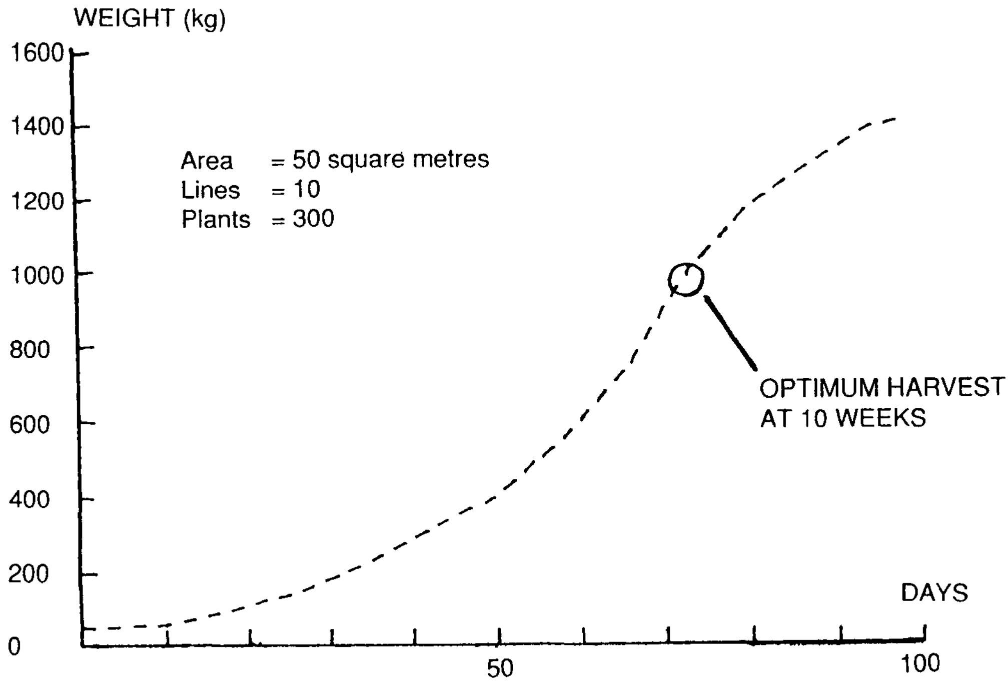

Figure 4. Growth of *Eucheuma alvarezii* var *tambalang* at Moi Reef, Rakiraki, Fiji. Modified from Prakash (1990).

some methods, the tie-ties may be left on the lines for the attachment of new seedstock, or the entire tie-tie may be removed with the plant, and the two separated later before the weed is dried.

Plants are air-dried, preferably on a bamboo platform away from sand and other materials. The ideal water content (30 to 35 per cent moisture) is achieved in 3-5 sunny days; the plants are then ready for packing in bags for transportation to the shipper where they are baled. Most buyers prefer that the content of foreign matter is no more than 2-3 per cent.

It is important that baling be done soon after drying; this allows for more prolonged storage without spoilage, reduces storage space, and allows for easier handling and shipping. In Fiji 100 kg bales are preferred.

ECONOMICS AND PROSPECTS

The future success of *Eucheuma* farming in the tropical South Pacific will depend heavily on world market prices and trends and the cost of freight. Although farming is technically feasible and the quality of South Pacific *Eucheuma* is high (McHugh and Philipson, 1989), there is little prospect, according to these authors, of the industry becoming fully commercialized in the South Pacific. *Eucheuma* farming does, however, have the continuing prospect of remaining as a valuable income supplement in the subsistence sector, providing a number of basic requirements can be met.

There is a need for the development of research in support of South Pacific seaweed aquaculture (McLachlan, 1992). Ideally, it should be centered in Kiribati in support of the most viable industry in the region. Research should focus on markets, economics and strain selection.

The volatility of the seaweed industry is such, however, that in a recent report, McHugh (1990) noted that there had been a significant turnaround in world prices and demand for carrageenan, with the price more than doubling in a relatively short period of time. New uses for carrageenan, combined with the entry of new markets (such as that of the People's Republic of China) and poor productivity in the Philippines owing to weather conditions, led to a shortage of raw material and an increase in price. There is every indication that this trend will continue for several more years. Nevertheless, Nelson (1988) recommended caution in the development of any seaweed industry in the region, with particular reference to the need for designing strategies for penetrating existing markets.

Production of *Eucheuma* is 51,000 mt per year in the Philippines, and 14,000 mt per year in Indonesia. McHugh (1990) suggests that Pacific countries can expect to be only minor producers in the short - to medium-term. They will, however, be able to market a good product in light of the fact that there is presently an annual shortfall in carrageenan production world-wide. In his analysis of the prospects for the industry in the South Pacific, McHugh (1990) provides a detailed review of the factors that should be considered by Pacific islands countries when examining the feasibility of *Eucheuma* cultivation. He stresses the importance of the following:

1) the minimum income that a seaweed farmer will accept.
2) the local costs of establishing a seaweed farm.
3) domestic costs (*e.g.* transport, quality control).
4) costs for the exporter (*e.g.* inspection, sorting, baling, shrinkage losses, overheads, financing costs, *etc.*), and
5) world prices and currency exchange fluctuations.

The above factors cannot be generalized, but they must be continually assessed for each individual country. Pilot farms are important and the need for farmers to diversify their income to reduce the risk of failures cannot be overemphasized. McHugh (1990) provides a formula that can be applied to the above considerations.

Changes in the processing of *Eucheuma* and the establishment of processing plants nearer to the South Pacific (*e.g.* in the Philippines) will substantially alter the economics and feasibility of *Eucheuma* cultivation in the longer term.

A major influence on the market has been the increasing use of semi-refined carrageenan (SRC), also referred to as seaweed flour. This product is relatively simple to produce (McHugh and Philipson, 1989) and is gaining increasing use in the industry. One hundred tonnes of *Eucheuma* (38 per cent moisture content) yields 25 to 28 mt of SRC; shipping costs are greatly reduced. Chips or granules can be produced for production of refined carrageenan, although a large percentage of SRC is ground to a fine powder and directly used in the manufacture of pet food and air freshener gels. World production of SRC in 1990 was 7,600 mt. Production of SRC is now carried out in the Philippines, and Lewis *et al.* (1988) describe the increasing use of SRC and its major impact on the carrageenan market, an impact that is likely to continue to grow.

One of the most important recent developments is the introduction of a new carrageenan product, Philippine Natural Grade (PNG; Ragan, 1991; Borja *et al.*, 1991). This is currently overtaking the production of other carrageenan products in the Philippines and is having a major impact on the food processing industry world-wide. Various agencies, including the United States Food and Drug Administration (USFDA), are examining PNG's acceptability as a food additive (Ragan, 1991; Sumption, 1991).

The development of PNG is entirely the result of Philippine research and technology (Borja *et al.*, 1991). *Eucheuma* is air-dried to a moisture content of 38 to 45 per cent, alkali treated and heated. After removal of the aqueous alkali the material is washed and the gel reduced in size by cutting equipment. It is then dried in enclosed mechanical bin dryers, Taiwan dryers, or microwave ovens. The final product is then sieved and blended in an enclosed area, before being alcohol or microwave sterilized prior to packaging (Borja *et al.*, 1991).

Since 1988 the international sale of PNG has increased from 58 per cent of the total Philippine seaweed exports, to 63 per cent (1990), valued at US$32.2 million. Food processors are finding many new applications for PNG, the foremost being in meat products where it replaces food starch and other gums currently in use. The advantage of PNG is that its price (US$7-8 kg) is about half that of refined carrageenan. New research organizations are being set up in the Philippines to support the carrageenan industry, and the future in that country seems very bright. The prospects for *Eucheuma* farming are good, and the government of the Philippines has as a goal - the involvement of one million farmers in seaweed production by 1993. Currently, there are some 350,000 farmer-producers who, during 1990, produced 77,000 mt of dried *Eucheuma*, a doubling of production since 1985 (Borja *et al.*, 1991).

Production of refined carrageenan is much more complex. McHugh and Philipson (1989) and Lewis *et al.* (1988) describe the extraction process in detail. In principal, the carrageenan is dissolved out of the seaweed, with the residue removed by filtration. An average yield of 25 per cent carrageenan is obtained.

Carrageenan is widely used in food manufacturing, other industries and in pharmaceuticals. A summary of applications for carrageenan is provided in Table III.

V. SEAWEEDS FOR HUMAN CONSUMPTION

Seaweeds (or sea vegetables) have been a traditional human food source since pre-history, and their consumption is an important dietary element for many Pacific islands peoples. Chapman and Chapman (1980) provide a good overview of algae as human food, although they make no mention of the South Pacific islands. Abbott (1988a and b) and Abbott and Cheney (1982) have reviewed the uses of seaweed for food, and the volume of Lembi and Waaland (1988) contains several other articles about edible seaweeds. Reference is made in Adams and Foscarini (1990) to the use of edible seaweeds in some of the South Pacific countries.

Chapman and Chapman (1980) list more than 60 species of seaweeds that are consumed as human food, and this list is doubtless incomplete. Abbott (1988a) lists about 30 species favoured as food by humans. She notes that seaweeds used as human food fall into two broad categories: those that are collected from the wild and those that are cultivated. As there is no commercial cultivation of edible seaweeds in the South Pacific region, the entire crop is gathered from the wild and consumed by the gatherer or sold in local markets. Gordon-Mills (1986) has recommended that studies should be made of the possibility of farming *Caulerpa racemosa* in Fiji.

A number of Pacific islands fisheries jurisdictions routinely gather data on seaweed sales at local markets. For the South Pacific islands the most commonly consumed species are *Caulerpa racemosa* and *Codium* spp. (Chlorophyceae), *Hypnea* spp. and *Gracilaria* spp. (Rhodophyceae). These same species are also popular in Hawaii (and consumed by a variety of ethnic groups there (Abbott, 1988a). The most valuable, *Gracilaria*, has annual sales in Hawaii of at least US$80,000. Although the annual crop value has not been determined for Fiji, there has been an annual increase in the consumption of edible seaweeds (Table IV).

Species of *Gracilaria* have considerable potential in aquaculture and, in addition to its food value, are valuable sources of the phycocolloid agar. As pointed out by Abbott (1988a), it is surprising that, considering the price of dried *Gracilaria* (more than US$600 per mt) and the world shortage of agar, no large-scale farming has been undertaken in the South Pacific although it has been attempted in Taiwan and Vietnam (Price, *pers. comm.*). The study by Smith *et*

Table III. Uses of Carrageenan (Sources : Chapman and Chapman, 1980; Lewis *et al.*, 1988).

Industrial
Air freshner gels
Tertiary oil treatment
Cleaners
Enzyme immobilization
Electrophoretic and chromographic media

Medical and Pharmaceutical Applications
Laxatives
Bulking Agents
Capsules and tablets
Lotions and creams
Shampoos
Ulcer products
Toothpastes
Antibiotic ice
Food Products
Frozen foods
Pastry fillings
Syrups
Bakery Icings
Relishes
Cooked and Instant Puddings
Chiffons
Dessert Gels
Fruit Juices
Sauces and gravies
Pimiento strips
Salad Dressings
Soft Drinks
Dairy Products (milk drinks, milk shakes, cheeses)
Eggnog
Beer foam stabilizer
Beer clarification
Fining and ageing of wines
Bread doughs
Meringues
Canned fish and meats (including pet foods)
Synthetic meat fibres

Table IV. Estimated sales of locally consumed seaweeds in Fijian Municipal Markets. Weights are given in mt. (wet weight) Source: Fiji Fisheries Division Annual Reports, in Prakash (1990).

	1982	1983	1984	1985	1986	1987	1988	Total
Caulerpa racemosa	6.08	6.64	5.07	4.12	4.79	6.16	5.88	38.74
Codium spp.	0.10	0.20	0.10	0.05	0.04	0.35	1.02	1.86
Gracilaria spp.[a]	4.20	4.54	4.30	4.05	4.54	4.69	5.12	31.44
Annual Total	10.38	11.38	9.47	8.22	9.37	11.20	12.02	
Grand Total								70.04

[a]Probably includes *Hypnea* spp. (G.R. South, *unpubl.*).

al. (1984) on *Gracilaria* cultivation in the Caribbean would be worth evaluating from a Pacific Islands standpoint.

The edible seaweed resource in Pacific islands countries should be determined through a comprehensive survey. The extent of the resource and its market value is unknown, the effect of seaweed gathering on the environment has not been assessed, and the potential for developing the edible seaweed resource in a sustainable manner has not been evaluated.

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