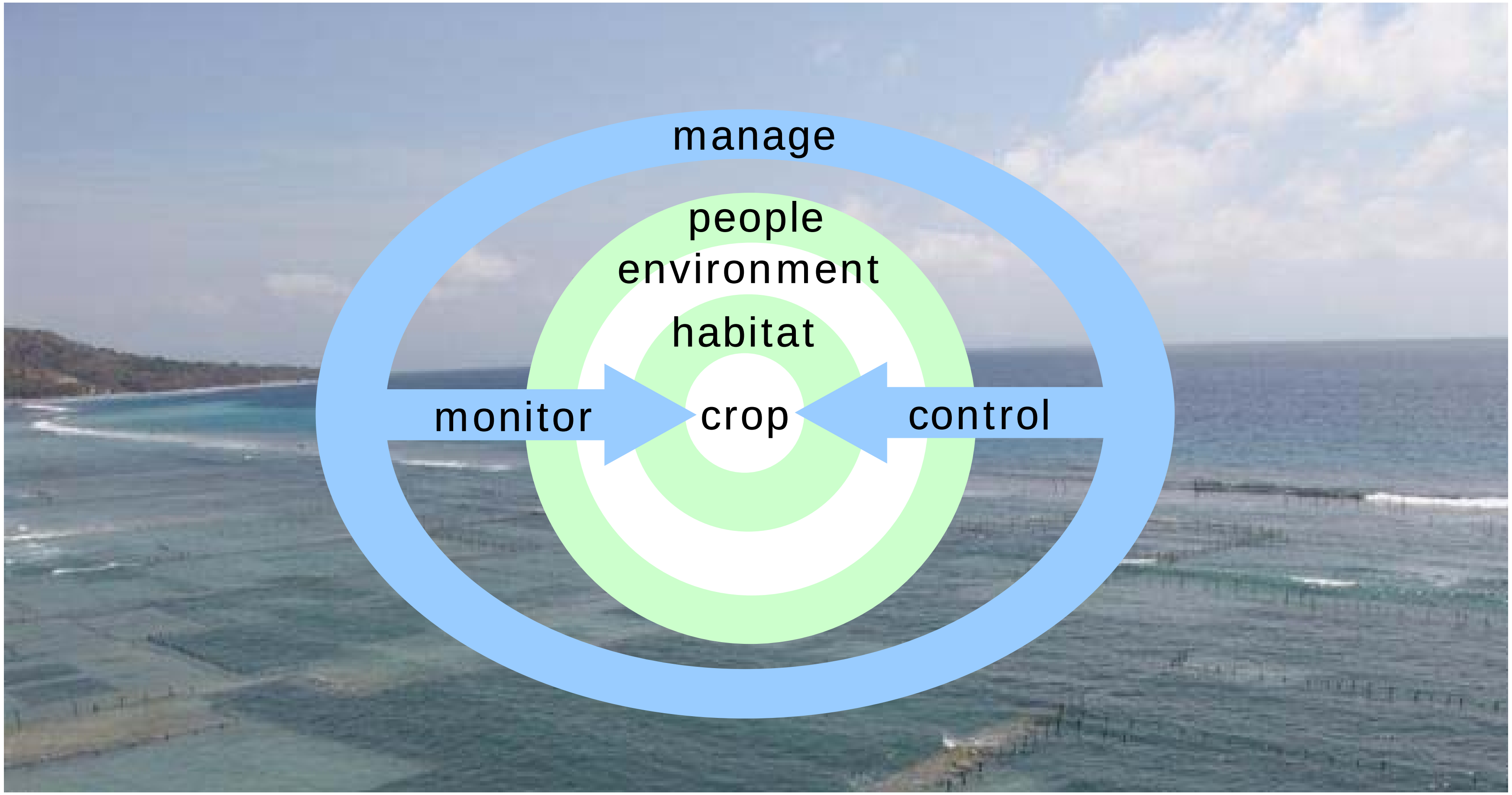
Good agronomy practices for Kappaphycus and Eucheuma:

including an overview of basic biology



by Iain C. Neish, SEAPlant.net Monograph no. HB2F 1008 V3 GAP

CONTENTS

BIBLIOGRAPHY Download: “*A Reference List for Commercially Cultivated Tropical Red Seaweeds*.” SEAPlant.net Monograph no. HB2G 1008 V3

GLOSSARY A-G

ADB - Asian Development Bank

Agar - Red algal galactan biopolymer produced by genera such as Gracilaria, Gelidium and Gelidiella.

Agronomics (marine) - The art or science of managing marine habitats for production of seaplant crops

Apical - Pertaining to the terminal segment or "tips" of fronds

ATC - Alkali-treated cottonii chips

AusAID - Australian Agency for International Development

Axenic - Uncontaminated and germ free (applied to cultures)

Basal - Pertaining to the oldest segment or "base" of fronds.

Biopolymer - Compound of high molecular weight synthesized by living organisms

BIMP-EAGA – Brunei, Indonesia, Malaysia Philippines East ASEAN Growth Area

Callus - Tissue that forms over cut parts of fronds

Carpospore - Diploid spores produced by carposporophytes that live parasitically on their mother plants

Carrageenan - Red algal galactan biopolymers produced by genera such as Kappaphycus, Eucheuma, Betaphycus, Gigartina, Chondrus and others.

Cisternae - Reservoirs or receptacles that hold fluid in the plant tissue

Clone - A group of organisms derived from a single individual

Conjugate - Fusion of two one celled organisms for reproduction where fertilization occurs

Coral Triangle – includes most of East Malaysia, Philippines, Indonesia, Timor Leste, Papua New Guinea and Solomon Islands

Cortex - The pigmented outer cell layer of a thallus or frond

Cottonii – Kappaphycus spp.

Cultivar – A clone derived from vegetative propagation originating from a single seaplant thallus.

DES - Dried Eucheuma Seaplants

Dioecious - Organisms that have male and female reproductive structures on different individual members of the species

Diploid - Having two similar complements of chromosomes

DKP - Dinas Kelautan dan Perikanan (Indonesian Department of Oceans and Fisheries)

EAI - East ASEAN Initiative of AusAID

ES - Eucheuma Seaplant (s)

End-user – an enterprise that utilizes as-is or further-processed ingredient building-blocks or ingredient solutions in goods that are purchased by wholesale and retail enterprises.

Eucheuma - "spinosum" of the trade; source of iota carrageenan.

Eucheuma seaplants – Betaphycus, Kappaphycus and Eucheuma

FAO – United Nations Food and Agricultural Organization

Frond - A branch of a thallus

Furcellaran - Red algal galactan biopolymer produced by Furcellaria spp.

Further processor – an enterprise that purchases -building blocks for further refinement.

Gamete - Mature haploid reproductive cell capable of fusion with another gamete to form a diploid nucleus

Gametophyte - Life cycle stage in many plants and algae; individual plant composed of haploid cells that produce gametes

GAP – Good Agronomic Practices

Germinate - To begin growing or developing

GMP - Good Manufacturing Practices

Golgi body - Golgi apparatus/body; a net-like mass of material in the plant cytoplasm that is a site of biopolymer synthesis

Gonimoblast - filaments extending from egg cell to carposporophytes

GTZ - Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ)

GLOSSARY H-Z

Habituate - To become used-to or adapted-to stimuli

Haploid - Having one complement of chromosomes

IBB - Ingredient building-blocks – products derived or extracted purely from one defined source of raw material and then sold to further-processors or solution providers.

IFC – AS - International Finance Corporation – Advisory Services

IFC-PENSA - IFC Small Business Development in Eastern Indonesia

IMTA - Integrated Multi-Trophic aquaculture

Indigenous – Originating in and characterizing a particular region or country.

JaSuDa – Jaringan Sumber Daya (Source Net), a program of SEAPlant.net.

Kappaphycus - "cottonii" of the trade; a seaplant source of kappa carrageenan

KITS - Knowledge + Information + Tools + Solutions

Macrophyte - Plants large enough to be readily seen by the naked eye

Macroalga - Non-vascular aquatic or marine plants of the phyla Chlorophyta, Rhodophyta and Phaeophyta; Large enough to be seen using the naked eye

Marinalg – World Association of Seaweed Processors (marinalg.org)

Medulla - The un-pigmented cell layer immediately below the cortex

Microalga - Non vascular aquatic or marine plants too small to be seen by using the naked eye

Monoecious - Organisms that have both male and female reproductive structures on the same individual

Morphology - Form and structure of the plant

Pericarp - The walls of a ripened fruiting body

Phenotype - A character or individual defined by its appearance and not by its genetic makeup

Phycocolloid - Complex polysaccharide biopolymers produced by algae (e.g. agar, alginates and carrageenan)

Propagule - A cutting or fragment of a seaplant thallus that is used for vegetative propagation of a crop

Protoplast - Actively metabolising membrane-bound part of a cell (as distinct from the cell wall)

RAGS – red algal galactan seaweeds (includes eucheuma seaplants)

RC - Refined Carrageenan

Rheology - Textural characteristics of a gel or solution.

Rhizoid - Root-like filaments by which a macroalga attaches to substrate; collectively may form a holdfast

Seaplant - Any photosynthesising organism that lives in seawater

Seaweed - Common name applied to most marine macroalgae

SFDM - Salt free dry matter

SGR - Specific growth rate expressed in percent per day

SIAP - Seaweed Industry Association of the Philippines

SPNF- Seaplant.net Foundation

Spinosum – Eucheuma spp.

SME - Small-medium enterprise

Sporophyll - Structure that produces reproductive cells called spores

Sporophyte - The life cycle stage in plants and algae that terminates in meiosis to produce spores

SRC – semi-refined carrageenan (a.k.a. processed eucheuma seaweed, PES or E407a)

Tetraspore - one of four asexual spores produced in a tetrasporangium

Thallus - The entire physical entity of a propagule or a whole plant

Uniseriate - Occurring in a single series

USD - United States dollar

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PREAMBLE

This monograph and its companion monographs in the HB2 series supersede and expand upon *The Eucheuma Seaplant Handbook Volume I : Agronomics, Biology and Crop Systems* (SEAPlantNet Technical Monograph No. 0505- 10A; ISBN 979 99558 0 7). Volume II of the Eucheuma Seaplant Handbook was never completed. Material that was to be included in that have been written up as other monographs in this HB2 series.

SEAPlant.net Foundation (SPNF) began as an initiative of IFC – Advisory Services under the PENSA I program that ended its five year term in June, 2008. During jointly funded work involving the PENSA program and GTZ (Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH.) it became clear that an integrated, ongoing and readily accessible body of information was necessary to facilitate and catalyse the development of seaweed farming as a component of integrated multi-trophic aquaculture (IMTA) in the BIMP-EAGA region in particular and in the Coral Triangle in general. GTZ therefore joined with SPNF to develop *A Practical Guide to Quality Assurance, Governance Systems and Good Practices for Tropical Seaweed-to-Carrageenan Value Chains with focus on developing harmonization and transparency in the BIMP-EAGA region of ASEAN in the Coral Triangle* (SEAPlant.net Monograph no. HB2D 1108 V1 GTZ). The practical guide is provided as a tool for negotiating the tangled web of rules, regulations, standards, tests and other requirements that increasingly make life complicated for industry stakeholders whether they be seaweed farmers, processors or end-users.

One of the objectives of the Practical Guide is to bring about the development of harmonized Good Agronomy Practices (GAP) for seaweed farming within the region. The present document is a draft that we hope will ultimately lead to GAP.

Regulations and standards for the aquaculture industry are at an early stage of development. Those for the specialty chemicals businesses are in a constant state of change and comprehensive standards for carrageenan and agar in the BIMP-EAGA region have yet to be adopted although draft standards are under development. Consequently this is a “living document” that is being updated periodically.

We heartily welcome suggestions and guidance from the users of the present monograph and the Practical Guide.

Iain C. Neish, October, 2008
Makassar, Sulawesi Selatan, Indonesia

<u>BIBLIOGRAPHY FOR THIS MONOGRAPH:</u> Please download: “*A Reference List for Commercially Cultivated Tropical Red Seaweeds.*” SEAPlant.net Monograph no. HB2G 1008 V3

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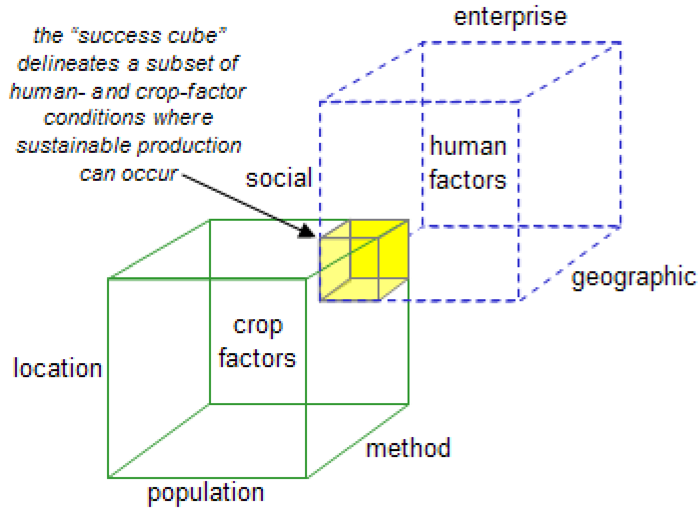
1.1. Overview of eucheuma seaplant agronomics

The development of commerce based on eucheuma seaplants is an outstanding example of farming that evolved from simple agronomic methods refined mainly by farmers in the field. This phenomenon has led to current production on the order of about 200,000 dry tons/yr from at least ten countries. Farm-gate revenues on the order of 150 M USD remain in rural coastal areas of tropical regions where eucheuma seaplant value chains are the main source of income to tens of thousands of people.

The commercial success of eucheuma seaplant farming is based on the fact that these plants produce vegetative thalli (propagules) large enough to be economically planted and harvested individually. This insight surfaced during experimental farming conducted in the Philippines during the late 1960s and the early 1970s. The history of exactly “who discovered what” is rather muddled since many individuals and entities vie for status as pioneers in the development of eucheuma seaplant agronomics. Initial success occurred in the Philippines during the early 1970s as a result of activities variously undertaken by individual farmers; Dr. Maxwell Doty's University of Hawaii teams; the Philippine Bureau of Fisheries and Aquatic Resources (BFAR); various Philippine universities; and Marine Colloids Inc. (now FMC Biopolymer). Further development of eucheuma seaplant farming within and beyond the Philippines was market driven. See SEAPlant.net Monograph no. HB2A 1008 V1 for an account of RAGS value chain development.

From the beginning eucheuma seaplant agronomics employed methods that attached individual propagules (cuttings) to supporting structures. Such methods are fundamentally different from the agitated slurries of unattached propagules popularly used to produce pond-cultivated Chondrus and other smaller seaplants. "Attach-to-substrate" agronomics are laborious but effective. Experimentation and cultivar screening are facilitated because individual cuttings can be labeled, removed, weighed and replaced at intervals. Comparisons between farming strategies and crop varieties are easily accomplished and farmers are able to innovate and expand farms rapidly**.**

Figure 1-1. The zone of feasible production options for eucheuma seaplant farming is a subset of options delimited by crop factors and human factors and depicted as a "success cube" below.



Crop factors critical to farm success include:

1. The population, which is the natural eucheuma seaplant population or the population of cultivated eucheuma seaplant seed stocks used as the basis of commercial production.

2. The method, which includes the agronomic and processing protocols followed to achieve commercial production within the economic goals set by a given enterprise.

3. The location which must be chosen carefully because good site selection will make or break any seaplant farming enterprise.

Human factors germane to farm success include:

1. Enterprise factors such as the structure of businesses and value networks.

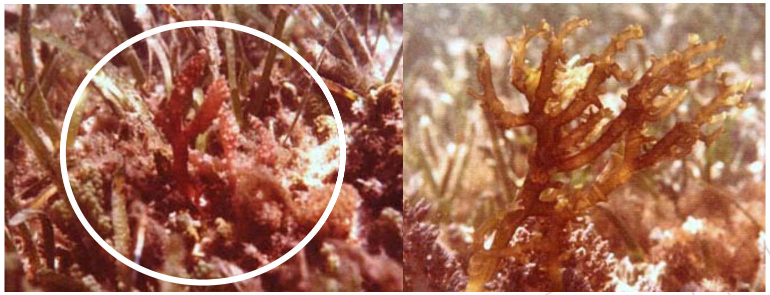
3. Social factors such as local norms, folkways and mores impacting farm productivity and trading patterns.

2. Geographic factors such as the distribution of farm enterprises and the logistic networks that connect value networks.

1.2. Natural distribution and dispersion by humans

Natural stocks of eucheuma seaplants species occur between about 20 degrees north and south of the equator – especially between the tenth parallels - in the Indo-Pacific. This zone is roughly defined by the winter isoclines of 21 and 24 degrees Celsius (Doty, 1987). The greatest abundance of eucheuma seaplant species seems to be in the algal reef areas of island archipelagos associated with Southeast Asia. They generally grow interspersed with corals and at first glance can often be mistaken for corals. There are also outlying species with relatively localized distributions.

Plate 1-1. Wild Kappaphycus spp. in the Southern Sulu Sea (1977).



Three northern outliers are *Eucheuma uncinatum* in the Gulf of California, E. isiforme in the Caribbean and E. amakusaensis in southern Japan. There is also E. deformans from Lord Howe Island and E. speciosum (Sonder) J. Agardh in southwestern Australia as well as E. platycladum (Schmitz) and E. odontophorum (Boergesen) in Tanzania and Mauritius, respectively. Doty (pers. comm) suggested the possibility of biogeographic distribution changing in response to crustal changes in the earth. The species in Australia, aside from those at its most northward edge, are mostly unique and seem to have been developed with mixtures of genomes from species further north. Doty noted that there appeared to be unlabeled specimens in herbaria that did not fit into the specific concepts ordinarily recognized among commercial species (Doty, 1988). Eucheuma serra is found nested well within the borders of the distribution of E. denticulatum and Kappaphycus alvarezii is within the distributional borders of K. striatum.

Eucheuma seaplants are robust and are easily transported if they are kept moist with seawater and are held within a temperature range that does not harm them. Under such conditions propagules can live for several days. Biomass on the order of tens of grams can be propagated to yield thousands of tons of material that form the basis of regional industries.

Eucheuma seaplant strains occurred naturally or have been dispersed by human activity to the point where marine out-plantings have occurred in at least 29 countries or territories (Table 1-1). Most commercial activity is within the natural range of eucheuma seaplants but there have been several recorded instances where species have been transplanted beyond their natural ranges.

It is often difficult to determine whether cultivars originated from indigenous populations or were introduced from elsewhere. Some factors that complicate such determinations are:

1. **The morphological plasticity** of eucheuma seaplants;
2. **The profusion of cultivars** (a.k.a. “strains” or “varieties”) with unknown origins;
3. **Limited knowledge concerning the natural distribution** of eucheuma seaplants prior to dispersion by human cultivation activities;
4. **The paucity of comprehensive historical records** concerning the species’ dispersion by humans.

Recent scientific studies are beginning to shed light on strain relationships. Advanced techniques enable the elucidation of differences in DNA and carrageenan characteristics (Aquilan *et al*, 2003; Zuccarello *et al*, in press).

Such work is at its early stages. Much more must be done before clear “family trees” and bio-geographic relationships can be established. Even the commercial utility of different cultivars has not yet been clearly differentiated. Some processors are willing to process certain strains and others are not. Many commercially significant differences may not be due to strain characteristics at all. They may be the result of culture conditions or post-harvest treatment.

1.3. Commercial distribution and development activity

Table 1-1 A. Eucheuma seaplant cultivation has been tried in at least 29 countries as shown below.

Country	'000 km (%) of coast	Year started	Sources
China	**15.3 (1.81)**	**1985**	Wu *et. al.* (1988)
India	**7.0 (0.83)**	**1989**	Mairh et. al. (1995)
Indonesia	**54.7 (6.48)**	**1975**	Adnan & Porse (1987)
Madagascar	**4.8 (0.57)**	**1998**	Ask & Corrales (2002)
Malaysia	**4.7 (0.55)**	**1977**	Doty (1980)
Philippines	**36.3 (4.30)**	**1971**	Doty & Alvarez (1973)
Tanzania	**1.4 (0.17)**	**1989**	Lirasan & Twide (1993)
Totals			
Brazil	7.5 (0.89)	1995	de Paula *et. al.* (1998, 1999)
Cambodia	0.4 (<0.1)	2000	Pers. Obs. of author
Cuba	3.8 (0.44)	1991	Serpa-Madrigal *et. al*. (1997)
Djibouti	0.3 (<0.1)	1973	Braud et.al. (1974, 1978)
Fiji	1.1 (0.13)	ca.1978	Prakash (1990)
French Antilles	0.1 (<0.1)	1978	Barbaroux et.al. (1984)
French Polynesia	2.5 (0.29)	ca.1985	Doty (1985a)
Guam	0.1 (<0.1)	ca.1985	Doty (1985a)
Honduras	0.8 (<0.1)	1978	Neish (pers.com.)
Japan	29.8 (29.75)	1983	Mairh *et. al.* (1986)
Kenya	0.5 (<0.1)	1996	M. Fazal, (pers. Comm.)
Kiribati	1.1 (0.13)	1977	Russel (1982)
Maldives	0.6 (<0.1)	1986	de Reviers (1989)
Micronesia	6.1 (0.72)	ca.1985	Doty (1985a)
Myanmar	1.9 (0.22)	2000	Pers. Obs. of author
Samoa	0.4 (<0.1)	ca.1978	Doty (1978a)
Solomon Islands	5.5 (0.65)	1987	Smith (1990)
Tonga	0.4 (<0.1)	1983	Fa'anunu (1990)
Tuvalu	0.1 (<0.1)	1977	Gentle (1990)
USA (Hawaii)	0.2 (<0.1)	1971	Doty (1985a,b)
Venezuela	2.8 (0.33)	1996	Rincones & Rubio (1999)
Vietnam	3.4 (0.40)	1993	Ohno *et. al.* (1995, 1996)

Table 1-1 B. Estimated eucheuma seaplant production volumes for 2003 were estimated to be as follows:

Country	*Kappaphycus* mt/yr (%)	*Eucheuma* mt/yr (%)	Develop Status
China	**800 (0.7)**	**nil**	**expand**
India	**200 (0.2)**	**nil**	**expand**
Indonesia	**48,000 (42.0)**	**8,000 (35.7)**	**expand**
Madagascar	**300 (0.3)**	**400 (1.8)**	**expand**
Malaysia	**4,000 (3.5)**	**trace**	**expand**
Philippines	**60,000 (52.5)**	**10,000 (44.6)**	**contract**
Tanzania	**1,000 (0.9)**	**4,000 (17.9)**	**static**
Totals	**114,300 (100)**	**22,400 (100)**	
Brazil	small/variable	nil	static
Cambodia	small/variable	nil	expand
Cuba	small/variable	nil	static
Djibouti	nil	nil	ceased
Fiji	small/variable	nil	static
French Antilles	nil	nil	ceased
French Polynesia	nil	nil	ceased
Guam	nil	nil	ceased
Honduras	nil	nil	ceased
Japan	nil	nil	ceased
Kenya	small/variable	trace	static
Kiribati	small/variable	nil	static
Maldives	small/variable	nil	static
Micronesia	small/variable	nil	static
Myanmar	small/variable	nil	expand
Samoa	ceased	nil	ceased
Solomon Islands	small/variable	nil	expand
Tonga	small/variable	nil	static
Tuvalu	small/variable	nil	static
USA (Hawaii)	nil	nil	ceased
Venezuela	small/variable	nil	static
Vietnam	small/variable	nil	expand

* Production figures from SuriaLink.com

** Legend: +++ = large; ++ = medium; +=small; - = none ? = in doubt

1.4. Spread of commercial activity

Cultivation of Kappaphycus and / or Eucheuma is known to have been attempted or successfully undertaken in at least 29 countries (Table 1-1). An analysis of official import data from 2002-2006 for 34 countries active in the seaweed and hydrocolloid trades showed that 19 were sources of seaweed and seaweed products (Table 1-2).

The Coral Triangle accounted for almost 86% of volume and 85% of value of tropical seaplant production. Official export data from Indonesia, Malaysia and the Philippines showed that import data from the basket of countries included in Table 1-2 accounted for 82% of reported export volume and 67% of reported export value from 2002-2006. The period 2000-2006 was characterized by tight supplies of Kappaphycus but adequate supplies of Eucheuma and Gracilaria.

Estimates of seaweed production in support of exports from the Coral Triangle indicated that by 2006 Indonesia production was about 100,000 dry tons and 2006 Philippine production was about 50-60,000 dry tons. Most of this was Kappaphycus. (From SEAPlant.net Monograph no. HB2B 0808 V2).

Table 1-2. Tropical countries known to have been sources of seaweed and seaweed hydrocolloids from 2002-2006. Note that Fiji is known to have exported some Kappaphycus during the reporting period but none appeared in these statistics. Also India is known to have exported several hundred tons of Kappaphycus since 2003 but these shipments are lumped with other products in the customs data so exact quantities were not known.

SOURCE	TOTAL TONS	% TONS	SOURCE	K USD CIF	% USD CIF
Indonesia	238,734	49.2	Philippines	251,605	51.2
Philippines	170,564	35.2	Indonesia	151,273	30.8
Tanzania	29,756	6.1	Taiwan	30,091	6.1
Peru	14,278	2.9	Malaysia	14,302	2.9
Vietnam	8,292	1.7	Peru	12,343	2.5
Malaysia	5,369	1.1	Tanzania	11,392	2.3
Thailand	5,191	1.1	Thailand	7,526	1.5
Cambodia	3,451	0.7	Tonga	3,144	0.6
Taiwan	2,553	0.5	Vietnam	3,128	0.6
Madagascar	2,365	0.5	Cambodia	2,165	0.4
Tonga	2,061	0.4	Madagascar	1,454	0.3
Kiribati	576	0.1	Brazil	1,139	0.2
Brazil	532	0.1	Senegal	554	0.1
Solomon Islands	471	0.1	Namibia	479	0.1
Namibia	374	0.1	Solomon Islands	358	0.1
Senegal	161	0.0	Kiribati	346	0.1
Dominican Republic	57	0.0	Cuba	339	0.1
Sri Lanka	44	0.0	Dominican Republic	73	0.0
Cuba	18	0.0	Sri Lanka	67	0.0
	484,850			**491,776**	

1.5. Moving cultivars among regions

Human actions have had a major impact on the distribution and abundance of eucheuma seaplants. Zemke-White (2004) pointed out that adverse impacts from accidental algal introductions are quite well documented but there have been few studies on the intentional introduction of seaweeds for culture.

Kappaphycus alvarezii and K. striatum seem to have been narrowly restricted to the southernmost Sulu Archipelago, the Celebes Sea and Biak na Belau north of the equator until they became widely distributed by man (Doty; *pers.comm*.). Doty speculated that "cottonii" may have been introduced to Ponape during Japanese occupation of the area. Since then Kappaphycus has been introduced to at least 19 countries and Eucheuma has been introduced to at least 13 (Table 1-1).

Cultivars of Kappaphycus alvarezii and K. striatum seem to make up the bulk of eucheuma seaplant production. Although strains of Philippine origin seem to be the basis of most cottonii farming throughout the world there appear to be local cultivars that have been commercially grown in Indonesia and Malaysia. Cultivars of Kappaphycus have been moved around the world and so have Eucheuma spp. cultivars. For example E. denticulatum strains have been taken to the Lombok Straits area of Indonesia and have since spread throughout Indonesia. E. denticulatum has also spread via Singapore to Djbouti. K. alvarezii of Philippine origin forms much of the basis for cottonii farming in Indonesia but the substantial spinosum production of Indonesia is based primarily on strains originating from Flores. These plants have since spread to Sabah and the Philippines and seem to be widely cultivated in those regions now.

Recorded cases of eucheuma seaplant transplantations are numerous but undocumented cases appear to be much more abundant. A notable early example of recorded transplantation was the introduction of K. alvarezii and E. denticulatum to Hawaii by Doty. From Hawaii they have been taken to eastern and western Kiribati, Tonga, Fiji and elsewhere (e.g., to the Society Islands and temperate North America). Subsequently these species have been classified as "alien and invasive" algae in Hawaii (Conklin & Smith, in prep.).

For the most part transplantations of eucheuma seaplants appear to have been done without benefit of quarantine procedures. Such were the cases of Indonesia (Adnan & Porse, 1989), the Maldives (De Reviers, 1989) and Tanzania (Lirasan & Twide, 1993). In other cases quarantine procedures have been followed as in the Solomon Islands (Smith, 1990), Brazil (De Paula *et al.*, 1998) and India (Mairh, *pers. comm.*). Ask *et al.* (2001) have proposed procedures based on FAO guidelines and specifying that quarantine facilities should have the following characteristics:

1. **Isolation** from other aquaculture facilities.
2. **Structures** that prevent entry of marine organisms.
3. **Water supply** of good quality and independent source.
4. **Discharge systems** that effectively prevent the inclusion of biological material.

FAO guidelines suggest that plants should be quarantined for at least two weeks and should be examined at least daily to check for problems. Water should be changed at least twice per week and waste water discharged in a way that ensures no escape of aquatic organisms to local waters.

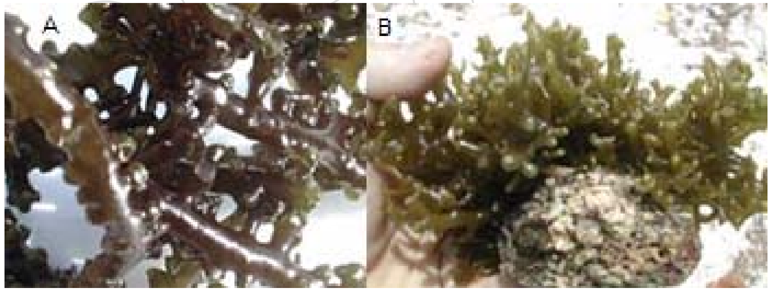
Kappaphycus is well known to "escape" from farms as large propagules fragment. Kappaphycus has been observed to produce tetraspores in sea cultures (Bulboa & de Paula, *in prep.*) and has been reported to establish free living populations (Conklin & Smith, *in prep.*). The impacts of such populations on local habitats differ among locations but Conklin and Smith present evidence that plants identified as Kappaphycus and/or Eucheuma and postulated to have been introduced into Hawaiian waters has overgrown and killed some endemic corals in Hawaii. Further study is underway to conclusively verify the true provenance of ancestral material for these populations.

1.6. Limitations to moving cultivars among regions

For eucheuma seaplants farmed in the sea breakage is inevitable and fragments fall to the sea floor. Many are eaten by grazers or fall to areas where they quickly die. Some survive and propagate as loose populations. Others are caught in catch nets or are picked from the sea floor by gleaners. In long-time cultivation venues such as Bali it is common practice for farmers to routinely practice such techniques and then to share in the revenue generated from sales of gleaned material. Broken or cut *Kappaphycus* thalli can fuse to each (Plate 1-6) so attached populations can occur and in certain conditions may propagate vegetatively (Conklin & Smith, *in prep.*) or possibly by sporulation (Bulboa & de Paula, *in prep.*).

Plate 1-4. These farm sites in Nusa Penida, Bali have catch nets installed. Broken propagules accumulate along the catch nets where they can easily be retrieved.

Plate 1-5. Broken *Kappaphycus* thalli fused to each other (A, below) and to a stone (B, below).



Transplantation of useful species to non-native sites is a contentious subject. Seaplant farmers must take into account the potential environmental, legal, political and social consequences of transplantations.

Zemke-White (in press) has reviewed the literature pertaining to impacts of introduced eucheuma seaplants. He pointed out that few adequately structured studies have been done on this subject and that results so far are inconclusive. It is clear, however, that Hawaii is an instance where Kappaphycus populations appeared to have little impact at first and have spread to the point of having noticeable impacts (e.g. covering coral) more than 25 years after their introduction (Zuccarello *et al.*, in press).

There are several attitudes and opinions concerning the issue of eucheuma seaplant introductions to regions where they are not indigenous. This has led to a variety of advocated or applied approaches to the regulation and management of introductions. The polar-opposite approaches are:

1. Tight limits -
According to this approach it is recognized that there is abundant production potential for eucheuma seaplants in regions where they are indigenous so there is no global commercial need to have them produced from regions where they do not occur naturally. Introduction to places where the eucheuma seaplants are not indigenous should be discouraged or forbidden

2. Loose limits –
According to this approach eucheuma seaplants should be introduced anywhere that there are willing farmer populations in regions where eucheuma seaplants can grow.

For locations outside the limits of indigenous eucheuma seaplant populations there is obviously a judgment call as to whether farming should be banned or whether a "happy middle ground" can be found that will enable local people to become eucheuma seaplant farmers.

1.7. Major tropical seaweed production trends

The main commercial use of eucheuma seaplants is as raw material for the production of red algal galactan (RAG) biopolymers known as carrageenan. The tropical eucheuma seaplant genera Kappaphycus and Eucheuma have become the main sources of carrageenan during the past two decades (Figure 1-2). Most cultivated tropical seaweed was RAGS from Indonesia and the Philippines (Table 1-2) and about 75% was Kappaphycus. See SEAPlant.net monographs no. HB2B 0808 V2and HB2E 1008 V1 for more details.

Figure 1-2. A graphic history of the production of carrageenan-source seaplants from 1961 to 2007. **Top (green):** Estimated production of the commercially cultivated "warm water" seaweeds Kappaphycus spp. + Eucheuma spp. In Malaysia, Indonesia, and the Philippines 1975-2007 (SEAPlant.net data) **Bottom (yellow):** Estimated production of commercially harvested wild "cold water" red seaweeds (mostly Chondrus crispus; some Furcellaria fastigiata) from France, Canada, Chile and the U.S.A. 1961-2001. (after FAO and Prince Edward Island Fisheries Dept. statistics).

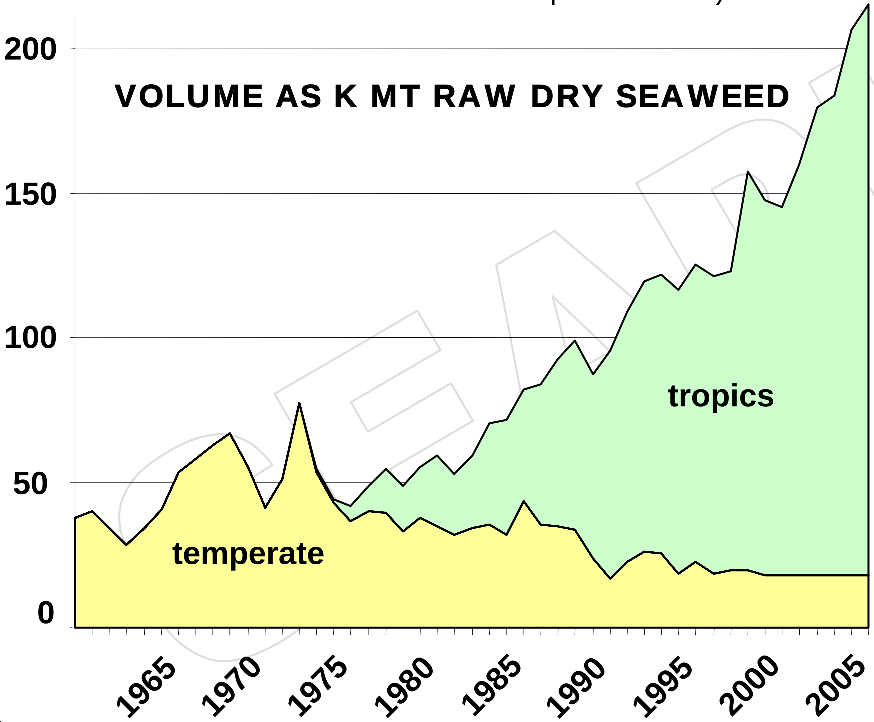
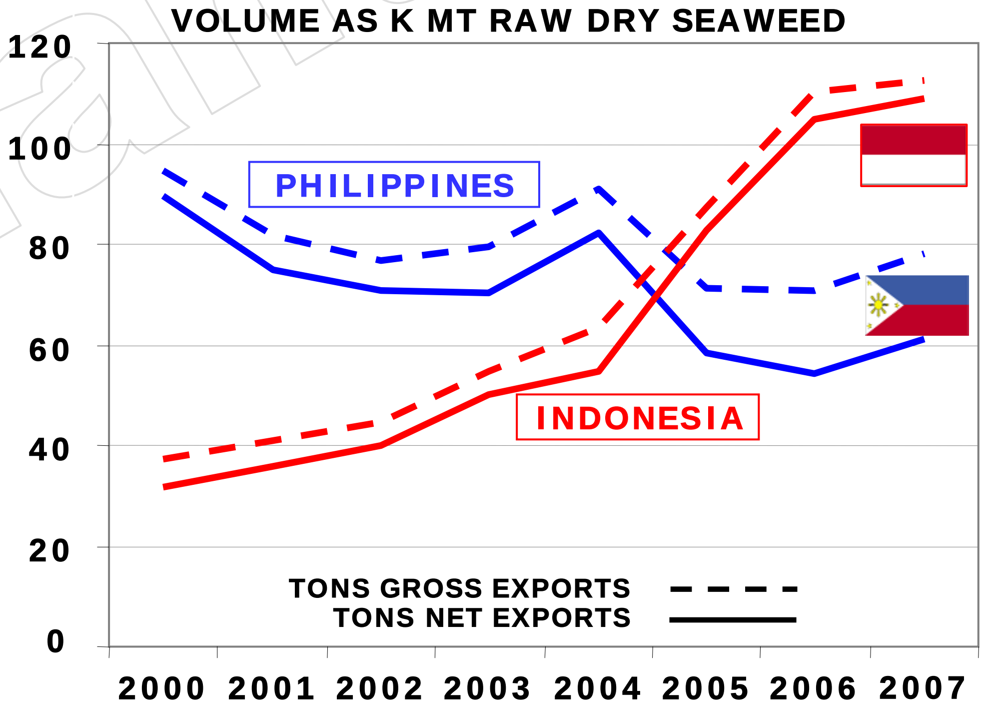


Figure 1-3. Indonesian annual seaweed volume rose from less than 40 K MT/yr to over 100 K MT/yr from 2000-2007. Philippine seaweed production declined from about 90 K MT/yr to less than 80 K MT/yr from 2000-2007. Most Philippine exports were as value-added carrageenan building block products or as blended ingredient solutions rather than as raw, dried seaweed. Most Indonesian exports were as raw dried seaweed. (From SEAPlant.net Monograph no. HB2B 0808 V2).



1.8. Evolution of RAGS value chains

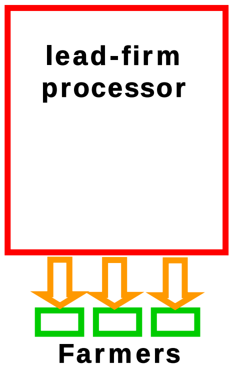
SEAPlant.net monograph no. HB2A 0808 V1 describes the implications of how value chain structure and development have evolved for RAGS value chains. During 2008 a preponderance of “market governance” value chain practices led to chaos in cottonii markets that was just beginning to settle down by October. It appears that the development of relational value chains may contribute to driving the innovation and growth necessary to meet the demands projected in Figure 1-5.

Figure 1-4. Governance systems that have been applied to RAGS value chains.

1970s – mid 1980s

Captive governance

vertically integrated enterprises that control value chain functions

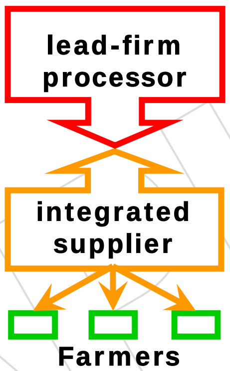


- ✓ Many small sellers few large buyers (oligopsony)
- ✓ Direct financial and technical support from processors
- ✓ Led to development of seaweed farming
- ✓ Philippines monopoly on raw material for carrageenan
- ✓ Buyers linked through Marinalg and alliances

mid 1980s - present

Modular governance

controlled by firms that determine product specifications, trade rules, etc.

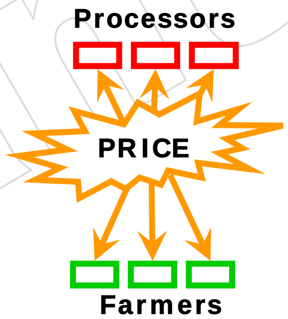


- ✓ Many small sellers
- ✓ Rapid market growth driven by SRC
- ✓ Farm development driven by price manipulation
- ✓ Some trader financing
- ✓ Indonesia develops as a significant source
- ✓ Major traders become processors

mid 1990s - present

Market governance

“arm’s length” transactions between buyers & sellers; little or no formal cooperation among participants

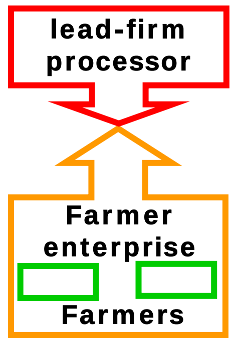


- ✓ Many small sellers
- ✓ Much “spot” selling... often in seller’s market
- ✓ Minimal farm development funded by traders and processors
- ✓ Growth largely from farmer self-financing
- ✓ Some support from aid & assistance programs
- ✓ Processors proliferate in Philippines, Indonesia & China

developing now

Relational governance

fairly autonomous decision making among participants; cooperation & alliances prevail

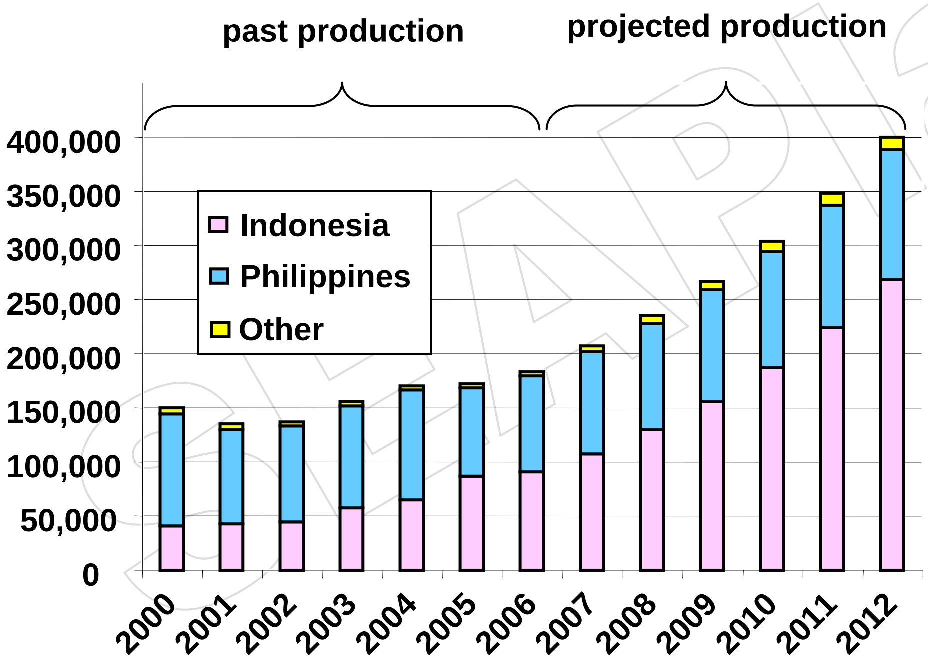


- ✓ Fewer & larger sellers
- ✓ Farm development driven by integrated aquaculture systems
- ✓ Market for RAGS raw materials diminishing in importance
- ✓ Processing sector consolidating
- ✓ New product lines developing
- ✓ Regionalisation of value chains

1.9. Demand projection for eucheuma seaplants

The data examined for SEAPlant.net Monograph no. HB2B 0808 V2 indicated an overall market growth from 2002-2006 of 8% in volume and 15% in value for seaweed and gum imports. Based on trade data analyses and models SEAPlant.net has developed projections for the overall RAGS market (Figure 1-5). This projected doubling in the requirement for RAGS seaweed raw materials over the next five years. Most of this requirement was for sources of agar and kappa carrageenan that can be made in semi-refined or gel-press process facilities.

Figure 1-5. Past and forecast production (in dry metric tons) for Kappaphycus, Eucheuma and Gracilaria from the Coral Triangle. (SEAPlant.net data). Data are expressed in terms of commercially dry metric tons of seaweed. Numbers were derived from trade data for export products so domestic consumption was not included. The economic model based was on supply, demand, and trade data. Expected growth of 13% was projected from 2008 to 2012



SEAPlant.net expects that most increase in production will come from the Coral Triangle region. The reasons for this are explained in "*Tropical Red Seaweeds as a Foundation for Integrated Multi-trophic Aquaculture (IMTA): Four propositions and an action plan for this major opportunity in the Coral Triangle.*" (SEAPlant.net Monograph no. HB2E 1008 V1). Regions where the expansion of production were deemed most likely to succeed those were:

1. There are no typhoons. In the Eastern Philippines typhoons have severely damaged farm areas several times during the past three decades. In recent years typhoons have begun to occur further south that they used to (e.g. in the Zamboanga Peninsula which was formerly considered to be typhoon-free).

2. Seasonality and incidence of diseases are minimal. Some regions exhibit distinctly outbreaks of the malaise known as "ice-ice". Within such regions disease problems such as epiphytes have been observed (Hurtado and Critchley, 2006).

3. Law and order prevails. The ARMM region of the Philippines is an example of a major seaweed growing region where production is curtailed because seaweed farmers have fled productive areas where excessive rents are levied by armed groups.

4. Farmers have rights over farm sites. One of the strengths of Indonesia is that government de-centralisation polices have put considerable control of seashore utilisation into the hands of the people who live there.

5. Infrastructure and shipping facilities are adequate. Domestic shipping costs tend to be high in the CT especially in farm areas most remote from major ports. This puts remote regions at a competitive disadvantage.

6. Business essentials are available & applicable. Throughout the CT business development services, access to finance, access to goods and services and other business essentials are lacking. Where business essentials have been provided seaweed farming has developed strongly.

1.10. Social impacts of eucheuma seaplant farming

Positive social impacts

For anyone connected with the development of eucheuma seaplant value chains it has been most gratifying to see the rapid and sustainable improvement in economic circumstances that has accompanied eucheuma seaplant farm development in the coastal zones of many tropical regions. Eucheuma seaplant production is an example of value chain development that builds on the strengths and traditions of coastal communities with creative participation by farmers. Positive social impacts include:

1. Direct income: Current production is thought to be nearly 150-200,000 dry tons/yr. Farm-gate revenues on the order of 6,000 USD/farm unit/annum are commonplace and a high proportion of the export price (typically about 90%) goes to the farmer.

2. Multiplier effect: A total of about 80-100 M USD of cash income remains in rural coastal areas of tropical regions where eucheuma seaplant value chains are the main source of income to tens of thousands of people. This cash can be directly applied to overall economic and social development.

3. Steady income: In the best cultivation regions crop production can take place year around. Harvesting and cash sales can take place virtually every day.

4. Opportunities for marginalized segments of society: Many seaplant farming activities require light labor that can be undertaken when time allows near to the residence of farmers. This creates income opportunities for women with care-giving responsibilities and also for old people.

5. Small-medium enterprises predominate: The seaplant farming and several other value-adding activities are inherently suitable for micro, small and medium enterprises.

6. A sense of stewardship develops: Seaplant farming can provide the means and foster the attitudes necessary for the conservation of local marine habitats and resources.

Negative social impacts

In and of itself participation in eucheuma seaplant value chains does not have unique negative social impacts but, as with other forms of rural crop production, there are abuses to guard against including:

1. Exploitative commercial relationships: Historically seaplant farming has been promoted in many regions by entrepreneurs who have advanced funds and planting materials to farmers. In some cases this practice has led the instances where farmers have become "locked in" to disadvantageous commercial positions.

2. Child labor issues: It is common practice, as in most agriculture, for children to participate in farming activities. One must ensure that they are not exploited in this capacity.

3. Family issues: Women generally play an important role in eucheuma seaplant farming and in some cases this results in instances where they go from having little income to becoming the main earner in a family. This can lead to marital tensions.

Figure 1-6 Seaplant farmers function under economic circumstances and that vary from place to place even within a single state or province. At the time of writing many farmers were in category "C" (below) with poor market access; finance unavailable or only available on usurious terms; and little decision-critical information.

Farmer access category	AAA	AA	A	BBB	BB	B	C
Free market access	+	+	+	-	-	-	-
Finance available… reasonable terms	+	+	-	+	+	-	-
Decision-critical information available	+	-	-	+	-	+	-

A key objective of SPNF is to get all seaplant farmers into category "AAA".

1.11. Environmental impacts of eucheuma seaplant farming

The three main environmental impacts caused by seaweed farming in the tropics.

The farming of eucheuma seaplants is by far the most extensive form of tropical seaplant farming. Zemke-White pointed out three main impacts of farming practices that are most strongly associated with crop production on or very near the sea floor, namely:

1. **Disruption of benthic community structure** by removal of macro-benthic organisms and cutting of sea grasses.
2. **Substrate abrasion and disruption** caused by crops coming into contact with the sea floor.
3. **Skewing of species composition** caused by the introduction of new sets of ecological niches due to the physical presence of seaplants and man-made habitats.

Environmental impacts are all-important for sustainable seaplant farming. Farmers ignore this fact at their peril.

The five categories of impact relevant to eucheuma seaplant production are:

1. **Primary farm impacts** caused by the effects of seaplant metabolism and demography.
2. **Secondary farm impacts** caused by wastes or other impacts from post-harvest treatment and handling of crops.
3. **Collateral farm impacts** caused by human activities that are directly related to seaplant farming including the installation of habitat systems; trampling of the sea floor; damage caused by the use of boats and vehicles; processing activities; and effluents.
4. **Indirect farm impacts** caused by the non-seaplant farming activities of farmers locating domiciles and work places near to seaplant farms.
5. **Direct processing impacts** caused by effluents, solid wastes and other aspects of processing activities.

1. **Zemke-White suggested that farming practices with definite negative impacts** on the local environments include trash and tying of anchor lines to live corals. Other possible negative impacts include shading of underlying habitats; structures built on coral reefs; changes in sedimentation; and improper treatment of waste water from production facilities.
2. **Possible positive impacts** could include increases in fish numbers; replacement of destructive activities by farming; and farmers gaining a sense of “stewardship” over coastal areas.
3. **Impacts with either positive or negative effects** include changes in primary production; and farms changing the nitrogen regime of the reef community.

Four ways of minimizing eucheuma seaplant farming impacts by using floating systems:

1. **New habitat is created** rather than existing benthic habitat being interfered with.
2. **Substrate is placed into the water column** where nutrients are most available.
3. **Benthic communities are left intact.** Planting eucheuma seaplants on or near the sea floor disrupts natural benthic communities and effects species diversity.
4. **Crops can be tended using minimally destructive methods.** The use of vessels, rafts and dive gear minimizes trampling of benthic habitats and organisms.

Plate 1-7. Tending seaplant crops from from boats can minimize adverse farming impacts. (Sulawesi Utara, 2004).

2.1. Taxonomic classification

Genus: Betaphycus   Trade name: gelatinae   Symbol: BE

Authority: Doty ex P.C. Silva   Type species: Betaphycus philippinensis Doty

Classification: Eukaryota, Phylum Rhodophyta, Class Rhodophyceae, Subclass Florideophycidae, Order Gigartinales, Family Areschougiaceae.

Genus: Eucheuma   Trade name: spinosum   Symbol: EU

Authority: J. Agardh   Type species: Eucheuma denticulatum (N.L. Burman) F.S.Collins & Hervey

Common names: Agal agal, Agal agal besar, Agar-agar, Agar agar besar, Agar agar pulau, Agar agar seru laut, Chilin-t' sai, Crude agar, East-Indian Carrageen, Eucheuma, Eucheuman, Java agar, Kirinsai, Makassar weed, Ruwe agar, Ryukyu-tsunomata, Singapore weed, Spinosum, Tosaka nori, Zanzibar weed

Classification: Eukaryota, Phylum Rhodophyta, Class Rhodophyceae, Subclass Florideophycidae, Order Gigartinales, Family Areschougiaceae.

Genus: Kappaphycus   Trade name: cottonii   Symbol: KA

Authority: Doty   Type species: n/a

Commercial species: alvarezii (ALV), cottonii (COT). inerme (INM), interme (INR), striatum (STT), procrusteanum (PRO)

Common names: Agal agal, Agal agal besar, Agar-agar, Agar agar besar, Agar agar pulau, Agar agar seru laut, Chilin-t' sai, Cottonii, Eucheuma, Eucheuman, Guso, Kirinsai

Classification: Eukaryota, Phylum Rhodophyta, Class Rhodophyceae, Subclass Florideophycidae, Order Gigartinales, Family Areschougiaceae.

Genus: Gracilaria   Trade name: gracilaria   Symbol: GR

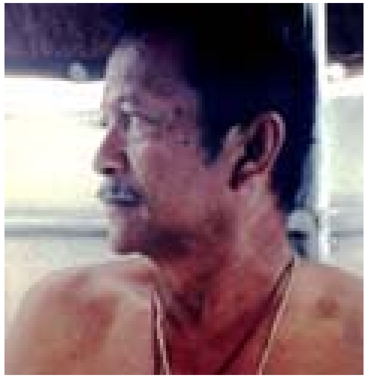
Authority: Greville   Type species: Gracilaria bursa-pastoris (S.G. Gmelin) P.C. Silva

Commercial species: asisatica (ASI), bursa-pastoris (BUR), caudata (CAU), changii (CHN), chilensis (CHL), cornea (COE), coronopifera (COO), crassissima (CRM), domingensis (DOM), edulis (EDL), eucheumoides (EUC), firma (FIR), fisheri (FIS), folifera (FOL), gracilis (GRA), heteroclada (HET), howei (HOW), lemaneiformis (LEM), longa (LON), pacifica (PAC), parvispora (PAR), salicornia (SAL), tenuistipitata (TET), verrucosa (VEU).

Common names: Agar-agar Caocaoyan, Agar agar (Agal agal) kecil, Ceylon moss Chinese moss Fen tsai, Gulaman, Gulaman dagat

Classification: Eukaryota, Phylum Rhodophyta, Class Rhodophyceae, Subclass Florideophycidae, Order Gracilariales, Family Gracilariaceae.

Plate 2-1. The specific name "alvarezii" as applied to Kappaphycus alvarezii Doty commemorates the late Vicente (Vic) Alvarez (below, ca. 1991). Vic was a pioneer in the methods of cottonii agronomics. He was a good companion and a true friend to many seaplant people including the author.



Comprehensive lists of common names , generic & specific names can be found at www.algaebase.org

Eucheumatoideae species of commercial significance are notoriously variable in form. Many cannot be distinguished on the basis of one specimen or collection without further taxonomic study. Since the commercial value of eucheuma seaplant species is related to the characteristics of biopolymers that they synthesize the infrared absorption by their gels has come to be a measure of differences among genera and species (Santos, 1989). The generic names "Kappaphycus" and "Betaphycus" reflect the types of carrageenan generally associated with the genera in question.

About eighteen to twenty species may be distributed among the four sections of the genus Eucheuma on the basis of their phylogenetic characteristics. Members of the section Cottoniformia feel different from the rest of the tribe. When alive they are turgid and when bent they will snap or break like a fresh carrot. When dry they are without spines and have a texture somewhat like sisal rope. Very dry material may be covered with salt (KCl) crystals. Among Kappaphycus species young primary branches generally turn upward and are relatively blunt, especially in young specimens of K. striatum. Branching is never truly opposite and the branches may be in pinnate series in part of a thallus, especially on long branches. New branches often arise from the dimly lit interior of dense thalli then grow toward the light, especially among cultivated plants growing on suspended lines. On the other hand, some species may be strongly compressed. Doty (1988) and Santos (1989) treated this section as the distinct genus Kappaphycus Doty.

Plate 2-2. Species in section Gelatinae (right) tend to grow in very turbulent, active water and seem to be unusually tough. They are compressed, flattened and have noticeable segmentation on some branches.

Plate 2-3. Many Eucheuma species are conspicuous for their spines (right). They often have long, cylindrical branches (e.g. E. denticulatum) or slightly compressed ones (E. serra) . Opposite branches are common. E. serra usually has bilateral spines rather than whorls. It appears to be a shallow-water form that has developed such characteristics in response to bright light and low water motion.

For reason of their location two species, E. isiforme (C. Agardh) J. Agardh and E. uncinatum Setchell & Gardner, are relatively well known through the work of Harvey (1853), Dawson (1961), Setchell & Gardner (1924) and a series of more recent investigators including D. P. Cheney, C. J. Dawes, James N. Norris and P. W. Gabrielson. These species generally have odd life cycles and their spines tend to be irregularly scattered. There are other less well-known members of this section that are very different in form. Doty (*pers. comm.*) suggested that they should be set off in discrete subsections. The cystocarps are borne subterminally on special branchlets or determinate spines and consequently these species often bear spines asymmetrically.

Eucheuma section Anaxiferae holds the species Eucheuma arnoldii Weber-van Bosse and E. amakusaensis Okamura. These are distinguished by a lack of differentiation in the central axial regions of their segments and by indeterminate vegetative growth of the sexually fertile branches. These are initially spine-like and produce cystocarps subterminally. This indeterminate growth appears to bring mature cystocarps to the surface of mature segments. Possibly, as in E. isiforme (Gabrielson, 1983), it is initiated in subapical papillae.

Click to table of contents

2.3. Taxonomic characteristics

Table 2-2A. Characteristics of typical species in the major sections within the Tribe Eucheumatoideae sections Cottoniformia and Eucheuma. (After Doty, unpublished).

Eucheumatoideae section Cottoniformia	**Eucheumatoideae section Eucheuma**
1- Fronds of many forms but commonly cylindrical; simple blunt or spiny protuberances	1- Fronds cylindrical; spines simple; basal diameters less than axis thicknesses.
2- Protuberances irregularly arranged; in some cases appearing in vertical rows so segments become angular	2- Spines in regularly spaced pairs or whorls first, but later others may appear scattered
3- Branching irregular; sometimes irregularly pinnate; may be opposite or falsely dichotomous	3- Branches generally form whorls; often opposite; irregular or in pectinate series
4- Hyphal axial core usually present; not rhizoidal; cylindrical.	4- Axial core rhizoidal and cylindrical
5- Kappa carrageenan	5- Iota carrageenan
6- Cystocarps on main axes	6- Cystocarps on lateral axes
7- No cystocarp associated with laterals	7- Generally a terminal spine beyond cystocarp

Generally K. cottonii and K. procrusteanum are compressed and clearly distinct due to the dorsoventral flattening and prostrate habit of the former and the generally erect, flat-bladed nature of the latter. The tissues of Eucheuma comprise an outer cortex of radial filaments, a subcortical/medullary area and a central core. The outer cortex may contain as few as four cells in tetrasporic thalli (Doty, 1988) but there may be very many cells as in vegetative portions of Eucheuma speciosum (Harvey 1853). Generally the subcortical/medullary area is formed of large, thick-walled cells. Below the apex of true K. cottonii the axial region is made up of large cells that are not readily distinguishable from peripheral medullary cells. In most other species a core made apparent by small cells can be distinguished. In kappa-carrageenan producing species such as K. alvarezii these cells may be the thylles of Weber-van Bosse (1926).

Table 2-2.B. Characteristics of the typical species in the major sections within the Tribe Eucheumatoideae sections Gelatinformia and Anaxiferae. (After Doty, unpublished).

Eucheumatoideae section Gelatiformia	**Eucheumatoideae section Anaxiferae**
1- Fronds compressed; spines simple; basal diameters equal axis margin thickness	1- Fronds cylindrical or dorsoventral and bearing compound spines
2- Spines in rows, marginally first and latter dorsally and ventrally on flatter faces or scattered	2- Spines often scattered, in whorls or covering the thallus in various arrangements or densities
3- Branches mostly marginal, pinnate, often opposite or irregular but not in pectinate series	3- Branches generally form whorls; often opposite or irregular
4- Axial core tortuous, hyphal and often flattened.	4- No hyphal or rhizoidalaxial core in cylindrical axes
5- Beta or other carrageenans	5- Iota carrageenan
6- Cystocarps on lateral or pedical axes	6- Cystocarps on main axes
7- Often several spines on cystocarp; sometimes none	7- Ultimately no spine on cystocarp

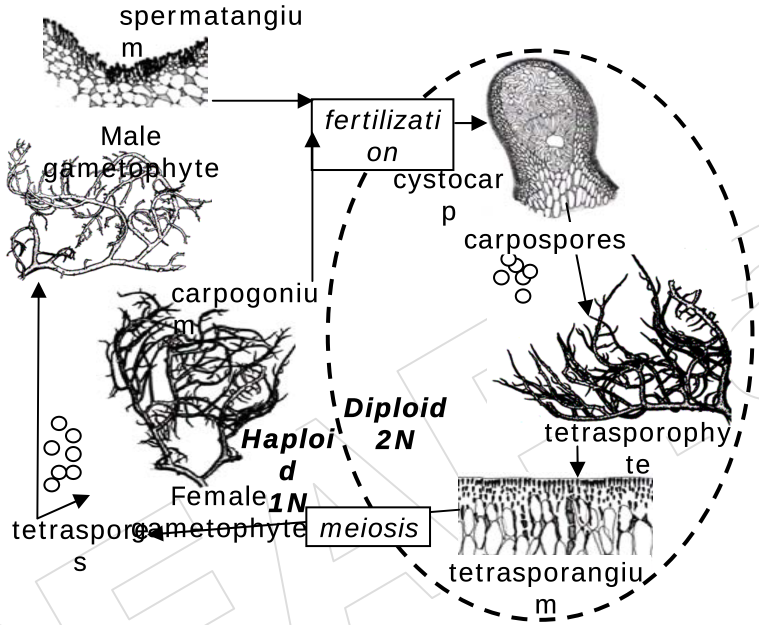
Rhizoids in E. denticulatum dominate the central axial region. Small cells may be conspicuously mixed with large cells, depending on the species. Thylles arise by budding yeast-like from large medullary or inner cortical cells and persist as small, somewhat elongated cells among large ones, especially in the central axial region. Kappaphycus displays no abundance of such cells in its mature axial tissues (Weber-van Bosse, 1913). Among iota-carrageenan producing species those in the section Anaxiferae similarly have a paucity of small cells among the large ones seen in an axis.

2.4. The triphasic life cycle

Perhaps the most significant agronomic breakthrough during the development of eucheuma seaplant cultivation was in the realization that one need not go through sexual cycles or spore production to propagate eucheuma seaplant crops. Vegetative clones proved to grow indefinitely and some varieties have been maintained in this way for more than thirty years.

In natural populations Eucheuma and Kappaphycus are generally considered to have a triphasic life cycle (Figure 2-1).

Figure 2-1. Schematic diagram of the triphasic life cycle.



Evidence from some species and sparse knowledge of male sexual thalli suggest other possible life histories. Since E. uncinatum is a seasonal species and the reproduction method is unknown for several other species of seasonal and/or restricted distribution it seems likely there are deviants from the ideal triphasic life cycle (Norris, 1985; Dawson, 1961; Cheney, 1975; Kraft, 1969; Azanza-Corrales, 1990).

Triphasic life cycles have gametophyte (N), tetrasporophyte (2N) and carposporophyte (2N) phases. They are called "triphasic" because the fertilized carpogonium produces a diploid carposporophyte rather than releasing carpospores.

The cystocarp is a single carposporophyte embedded in gametophyte tissues where it derives nutrients essentially as a parasite on the female gametophyte. Gametophyte tissue is separated into a pericarp (photosynthetic outer layer) and a colorless inner layer.

The carposporophyte produces and releases carpospores that grow into a second diploid generation which is a full-sized plant called a "tetrasporophyte".

Tetrasporophytes produce tetraspores in tetrasporangia. Meiosis occurs upon germination of the tetraspores.

Tetraspores grow into haploid male and female gametophytes that have a similar outward appearance to the tetrasporophytes (except for fruiting bodies if they become fertile).

Female gametophytes produce carpogonia at the tip of special carpogonial branches. Typically these are flask-shaped and have a long, thin neck called a trichogyne filament.

Fertilized carpogonia can produce several cystocarps due to nuclear transfers among connected filament cells.

Male gametophytes produce spermatia (non-flagellate male gametes) in the spermatangium. The spermatia move passively by water currents to fertilize carpogonia.

Fertilization occurs when spermatia fuse with the trichogyne tip. A channel is opened by enzymatic action to allow the spermatium nucleus to enter carpospores and several diploid spores are produced by mitosis of the zygote.

2.5. The triphasic life cycle - tetrasporangia

The reproductive contents of Eucheuma tetrasporangia tend to become arranged in series. Mature tetraspores seen *in situ* can be separated from each other and appear to be without walls. Yokochi (1983) studied the formation of tetrasporangia in B. gelatinae and found that liberation of their spores occurs during the warm season. There is a tendency for terminal spores to remain less than cylindrical and before discharge these are not broadly rounded even when nearly mature (e.g., Kraft, 1969, 1972; Gabrielson, 1983; Doty, 1988; Azanza-Corrales, 1990).

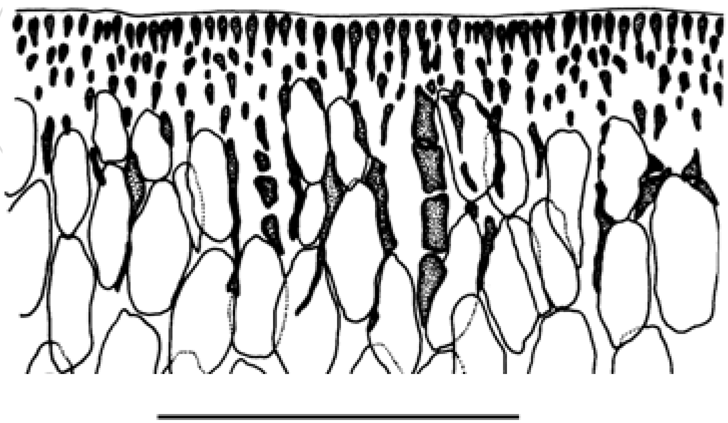
Eucheuma uncinatum appears to have terminal spores so small that they are presumed to be sterile. The ontogeny of tetrasporangia and tetraspores is difficult to follow despite their large size and abundance. The most mature tetrasporangia appear to be subterminally pitted. Their cell walls are hard to see by the usual staining techniques and seem to disappear though hydration into gels that lead to spore discharge.

Chondrus and several other genera of red algal galactan seaplants are known to produce different types of carrageenan in haploid and diploid life cycle phases. This is not known to occur among eucheuma seaplants.

Eucheuma seaplants do not exhibit significant morphological differences between haploid and diploid nuclear phases but many red algae have phases that undergo somatic development and exist as independent entities. Hughes & Otto (1999) have suggested that such organisms may exploit their environments efficiently through niche differentiation among phases. Even in isomorphic species with morphologically similar adults slight differences may play an important ecological role and help maintain haploid-diploid alternation of generations. Hughes & Otto developed a model for life cycle evolution that incorporates density-dependent growth and found that ecological differences between phases can lead to the evolution and maintenance of multiphasic life cycles.

During studies of Gracilaria gracilis Hughes & Otto (1999) concluded that an ecological explanation for haploid-diploid cycles is plausible even when there are only slight morphological differences among adults. Like Gracilaria gracilis, Kappaphycus and Eucheuma are haploid-diploid red alga with an isomorphic alternation of generations. Studies of eucheuma seaplant populations may reveal a similar phenomenon.

Figure 2-2. Tetrasporophytes of E. denticulatum (below) discharge spores that are spherical and separate from each other. (M.S. Doty image – bar = 50 micrometres).



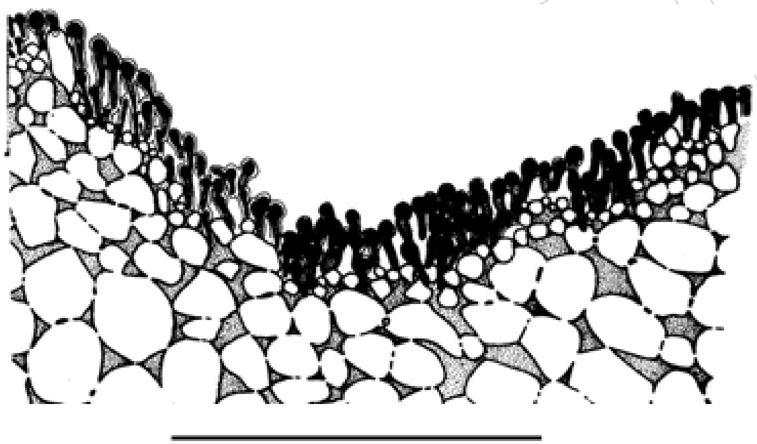
Tetraspores of Kappaphycus alvarezii readily adhere and grow on a variety of substrata but their development has been seen in few species since laboratory facilities are scarce where eucheuma seaplants are common. During his description of B. gelatinae tetraspore discharge and development Yokochi (1983) observed that spore discharge peaked in November and tetraspores were about 15-25 µm in diameter on discharge. Recently Bulboa and de Paula (*in prep*.) have reported the development of tetraspores in farmed Kappaphycus of the “sacol” cultivar during planting trials in Brazil.

2.6. The triphasic life cycle - gametophytes

Male structures are seldom seen among eucheuma seaplants except as reported in Eucheuma isiforme. According to Cheney (1975) and Dawes *et al.* (1974) they appear in superficial sori apparently on thallus segments. Azanza-Corrales (1990) has also observed this phenomenon in Kappaphycus alvarezii. Perhaps it is typical for the family.

The latter authors apparently found male structures in the proportions to be anticipated by simple genetic sex segregation. During earlier studies Kraft (1969) illustrated that these common but infrequently reported cortical structures were articulated hairs. However they are not yet generally accepted as male structures by many phycologists.

Figure 2-3. Longitudinal section of a K. alvarezii spermatangial sorus. (M.S. Doty image - Bar = 100 micrometres).



The female reproductive morphology of eucheuma seaplants is also little known. Kraft (1969) made a significant advance in describing the carpospores as solitary when he distinguished sterile suspending filaments between the fertile gonimoblast filaments In K. procrusteanum. Cheney (1975) illustrated the carpogonial branch of E. isiforme. The reproductive morphology of that species was later treated in detail by Gabrielson (1983). Further details concerning eucheuma seaplants reproductive structures were reported for E. serra, a close relative of the commercial "spinosum" by Gabrielson & Kraft (1984).

The work of Norris (1985), Doty (1988) and (Azanza-Corrales, 1990) has added various details about K. alvarezii reproductive structures. From such work it is apparent that the female structures of eucheuma seaplants are typically in spherical structures called cystocarps. These are readily visible as hemispherical to spherical bodies arising from the thallus surface. The distinctive morphogenesis of apical tip growth in E. isiforme has been described by Gabrielson (1983) and this morphogenesis, along with that to be inferred from Gabrielson & Cheney (1987), appears to set Eucheuma apart from closely associated genera of the Solieriaceae.

In the Eucheumatoideae fertile spine development is important systematically (Doty, 1988). In Eucheuma section Anaxiferae spines bear cystocarps subapically. These grow into branches of vegetative form. In other species they are not known to do so. Fertile spines in some species of section Eucheuma are morphologically distinct. They elongate and bear several cystocarps but remain slender. They appear to be sessile on the main branch axes as do those of Eucheuma section Anaxiferae but the derivation is different.

In Eucheuma speciosum tetrasporangia are borne in what appear to be deciduous special branchlets that may be rejuvenated (Doty, 1988). Doty considered this species to be among either the most highly- or the least-derived in the genus.

2.7. The triphasic life cycle - cystocarps

There is little published on the shedding of live carpospores and their development into fertile thalli (Azanza and Aliaza, 1999).

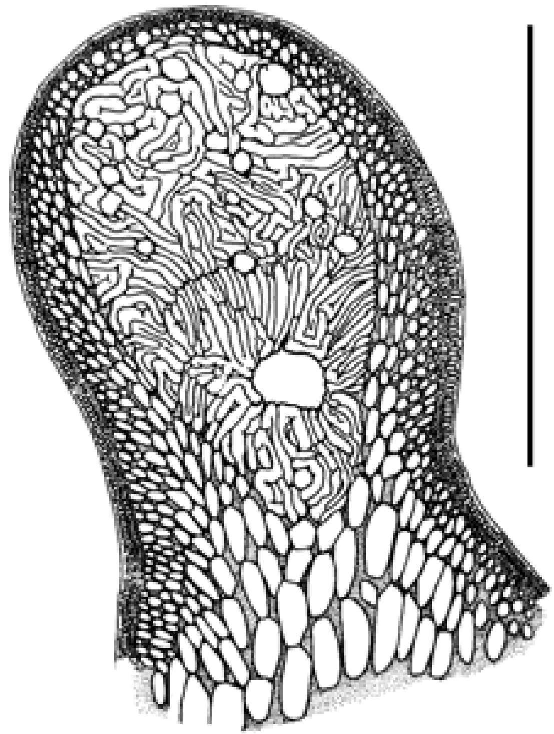
Carposporangium walls appear to dissipate around the forming spore. This gelation of diploid gonimoblast cell walls is not well understood but it may be a source of the force separating and pushing mature spores from the cystocarp. When they are shed carpospores will attach to glass and can be reared in dishes. The most complete description is for the infrequently seen species Eucheuma amakusaensis (Shinmura, 1975). Shinmura records the discharge of carpospores and illustrates their development to the point where they form an elongated cylinder about 0.4 mm tall. In K. alvarezii each diploid embryo of this type becomes a multicellular ball with rhizoids. Later the top protrudes so that juvenile thalli become pear-shaped and appear to be covered with a thick layer of gel through which long unstructured hairs are seen to radiate and protrude (Doty 1987). Laboratory conditions for K. alvarezii carpospore shedding have been studied by Azanza & Aliaza (1999) who showed the potential of using spores for farming of this species.

Within cystocarps the diploid spores, called carpospores, arise from gonimoblast filaments. These in turn radiate from a central fusion cell into a gel layer bounded outwardly by vegetative haploid cells and thence to the vegetative pericarp wall of the cystocarp. This feature is found, for example, among farmed representatives of Kappaphycus alvarezii (Azanza-Corrales, 1990).

Doty (1988) observed only one cystocarpic specimen of E. gelatinae but on this specimen in some cases a cystocarp was borne on a morphologically distinctive re-branched spine. If one follows the terminology of Harvey (1853) the cavity of the cystocarp may be spoken of as a placenta. The placenta includes filaments that radiate between the vegetative outer lining of the cystocarp lumen and the fusion cell (e.g., Okamura 1906,1936, Plate 276; Weber-van Bosse 1928; Kraft 1969).

From a detailed study of Eucheuma isiforme, Gabrielson (1983) suggested that placental filaments arise from the gonimoblasts and grow to the pericarp. However in some species they seem to pass through the concentric gel-filled space independent of the gonimoblast filaments and suspend the spherical fusion cell, thereby abetting its centric position and radial development. In Kappaphycus alvarezii these suspending filaments appear to be present before, and independent of, the branched gonimoblast filaments and may have a different origin (Doty, 1988).

Figure 2-4. Longitudinal section of K. alvarezii cystocarp. Bar = one micrometre. (M.S. Doty image).



2.8. Morphology and appearance

The kappa-carrageenan-bearing Kappaphycus species referred to as "cottonii" exhibit a highly variable gross morphology, color and general appearance. It is difficult to distinguish species among herbarium materials and plants can dramatically change appearance on being transplanted to new locations.

The photos shown in Plate 2-4 illustrate the degree to which gross morphology of Kappaphycus alvarezii can vary even within a single cultivar. All of the fronds shown in these photos were descended from a small sample that was brought to India from the Philippines in the early 1980s (Mairh *et al*, 1995).

The internal vegetative morphology of the eucheuma seaplants appears to be based on variations in the patterns of cells arising from longitudinal axial filaments (Doty 1985; Doty & Norris, 1985). In sections Cottoniformia and Anaxiferae the longitudinal axial filaments are soon transformed into somewhat elongated large round cells. In sections Eucheuma and Gelatiformia the fate of the long rhizoids occupying the axial cores must be different but just how is not yet clear.

The walls of eucheuma seaplants cells notoriously thicken with age and the relationships between them become hard to trace, though there are "pits" between them. Methods have been developed for precisely identifying where different carrageenans are located in the cell walls of eucheuma seaplants. These may lead to further elucidation of the biological role of carrageenan and the structure of cell matrices (Vreeland *et al.* 1987; Zablackis *et al.*, 1988). By such methods, florescin has been conjugated to carrageenan and the molecules are labeled when potassium is adequately present (Vreeland *et al.*, 1987).

Note: Descriptions on this and the preceding two pages were provided to the author by Maxwell S. Doty during discussions held in Honolulu on several occasions during the early 1990s. The author bears any responsibility for errors or omissions and welcomes amendments, additions and updates from those willing to contribute.

Plate 2-4. Kappaphycus alvarezii variability within a single cultivar (Tamil Nadu, India).

Kurusadai Is., 2001

Palk Bay., 2001

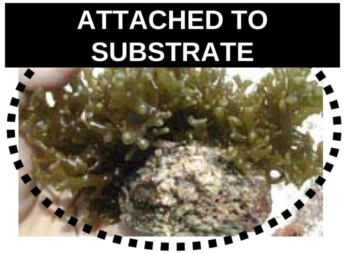
Mannar coast., 2001

Palk Bay., 2002

Munaikkadu 2002

Deviapattinam, 2002

Ervadi, 2002



Munaikkadu, 2002

2.9. Selection and improvement of cultivars

It seems that most, if not all commercial cultivars of eucheuma seaplant have been obtained by the continuous selection that occurs as farmers plant and harvest more or less on a daily basis. One of the first and most dramatic instances of field selection was when screening in the Sulu Sea led to discovery of the species that came to be recognised as K. alvarezii var. tambalang (Doty, 1985).

The K. alvarezii var. tambalang strain has been dispersed to several parts of the world and was once the predominant commercial strain. Since 1971 several genetically stable variants of K. alvarezii var. tambalang have been farmed commercially. The most common are known as the green, olive-green, red and brown types. Each strain has found favor in several farming areas and all are roughly equivalent in the quantity and quality of the carrageenan that they yield. Generally farmers select plants on the basis of their growth rate; indeed the process of long-term culling of vegetative plants leads inevitably toward such selection. In some instances aesthetic attributes may have played a part in strain selection. This seems to apply in the case of the "flower" variety which produces an impressive range of color variants.

During the 30 year history of eucheuma seaplant cultivation there has been a proliferation of strains that continues until today. Most of these appear to be of the species Kappaphycus alvarezii but one, the Sacol strain, may be more closely related to Kappaphycus cottonii (Aguilan *et al*., 2004) or possibly K. striatum.

To the casual observer color variants are the most obvious manifestation of polymorphic characteristic among the eucheuma seaplants. Several researchers (e.g. Dawes, 1992) have postulated that color variants should fare differently under different light conditions and many farmers contend that such is the case.

Plate 2-5. The photo right shows the range of color variants from the "flower" type grown in Manicahan, Zamboanga, Philippines (2004).

To date genetic work by classic hybridization techniques has not led to varieties of eucheuma seaplants that exhibit superior growth, farmability or carrageenan characteristics in comparison to cultivars descended from wild plants. The lack of widely recognizable male individuals and the large size of the thalli may prevent use of the conventional Mendelian genetic breeding methods used successfully with some other species of seaplants. However techniques to establish culture procedures that will result in a large number of cultivars and inexpensive propagation of Kappaphycus have been presented. For example Dawes and Koch (Azanza, *pers. comm.*) developed procedures for micropropagule and tissue culture to develop propagules successfully introduced to farms in the Philippines.

Reddy *et al.* (2003) in India have utilised *in vitro* somatic embryogenesis and the regeneration of somatic embryos to yield whole plants. Generation of propagules was successfully demonstrated when pigmented uniseriate filamentous calli of Kappaphycus alvarezii (Doty) were utilised as the basis for axenic cultures. More than 80% of the explants that they cultured using solidified Provasoli enriched seawater (PES) medium showed callus development.

There is a school of thought that advocates "genetic engineering" approaches to eucheuma seaplant cultivar improvement but this is a controversial issue.
Market resistance can be expected as a result of expanding global movement against genetically modified organisms (GMO) and many people value seaplants and their products largely because of their "naturalness". Some major users of carrageenan stipulate that GMO seaplants must not be used as raw material for manufacture of their ingredients. Fortunately there are still many natural gene pools to select from and there are no major problems with eucheuma seaplants that cry out for genetic engineering solutions.
There is still plenty of scope for programs of screening for new vigorous strains derived from natural populations and strains of interest can be retained in "gene banks".

Click to table of contents

2.10. Varieties

Since eucheuma seaplant farming commenced after 1970 there has been wide dissemination of strains around the world and a proliferation of cultivars as well; especially with Kappaphycus. Occasionally strains appear that have poor processing characteristics and these are usually eliminated from contention fairly quickly. In other cases there are mixed reactions to strain quality. Some processors are willing to process certain strains and others are not. One case in point is a "Bohol" type of cottonii that has been seen in food markets in the central Philippines and generally produces slender, tender branches but tends to yield carrageenan of dubious quality.

Since the Philippines has hosted commercial farming for the longest time it is there that the greatest number of *Kappaphycus* variants seem to have arisen. At least two variants of kappa carrageenan are found among these; the K. alvarezii type with a distinct infrared absorption peak at wave no. 805 and the K. cottonii types that lack this peak (Doty & Santos, 1978).

As comparisons of DNA characteristics are undertaken relationships among strains should become more clear. For example Aguilan *et al.* (2003) used DNA analyses to compare various strains of K. alvarezii, Kappaphycus sp. 'sacol' variety and Eucheuma denticulatum. Different strains of Kappaphycus alvarezii appeared to have similar banding patterns regardless of their differences in morphology and habit but Kappaphycus sp. "sacol" variety from Bohol showed a banding pattern more similar to K. cottonii than to K. alvarezii. Zuccarello *et al* (in press) have recently studied molecular markers in several strains of Kappaphycus and Eucheuma and provided insights into the taxonomy, genetic variability and sources of genetic variation among eucheuma seaplants. They found that Kappaphycus and Eucheuma are genetically distinct and perceived a genetic distinction between K. alvarezii and K. striatum Sacol strains. Some samples of K alvarezii from Hawaii and Africa were also found to be genetically distinct but commercially cultivated K. alvarezii from all over the world had a similar mitochondrial haplotype. For Eucheuma denticulatum most African samples were genetically distinct. It appeared that E. denticulatum clones have been selected from nature several times but this is less evident for cultivated K alvarezii.

The list below describes some of the Kappaphycus strains in commerce at the time of writing. This list is not comprehensive and the proliferation of strains continues.

1. Tambalang type

Long strands; typically fewer branches than flower; small to large diameter branches; generally thriving in deep water in northern areas of the Philippines but seldom seen in the Southern Philippines as "flower" now predominates there. Tambalang predominates in much of Indonesia, India, Sabah, Malaysia and Tanzania.

2. Flower type

Short strands; bundles of succulent multiple branches resembling a "flower". Found in shallow reef areas of the Philippines. Dominant strain in the Bongao/Sitangkai areas of the Philippines since 2000. Also seems to be appearing in South Sulawesi and Nusa Tenggara Timur in Indonesia. Subgroups include the larger "vanguard" type and the smaller "goma" (rubber) type which tends to have a rubbery texture and appearance.

3. Other types

Known by various names from region to region. These include apparent variants of the Tambalang type that include the long, thick "kapilaran" type and a second type called "vanguard". Smaller types include the "adik" (addict) type which may be a variant of "flower".

4. Bisaya type

Looks like a cross between tambalang and sacol types. Predominant form in the Bohol region of the Philippines.

5. Sacol type

Clumps of short multiple branches, with small diameter stems. Often found over sandy or muddy substrate such as that found near its source area of Sacol Island, Zamboanga, Philippines. Sold as salad vegetable in Cebu markets.

6. Sumba type

Long, thick strands. Rather like a coarse, robust form of the tambalang type. Originated in Sumba Island, Indonesia but now grown at several sites in Indonesia. Favoured by some farmers in Bali.

2.11. Varieties - Kappaphycus alvarezii (cottonii of the trade)

These photos were taken at Caragasan near Zamboanga City, Philippines during the same hour on December, 2003. They show the variation in appearance among some Kappaphycus alvarezii types.

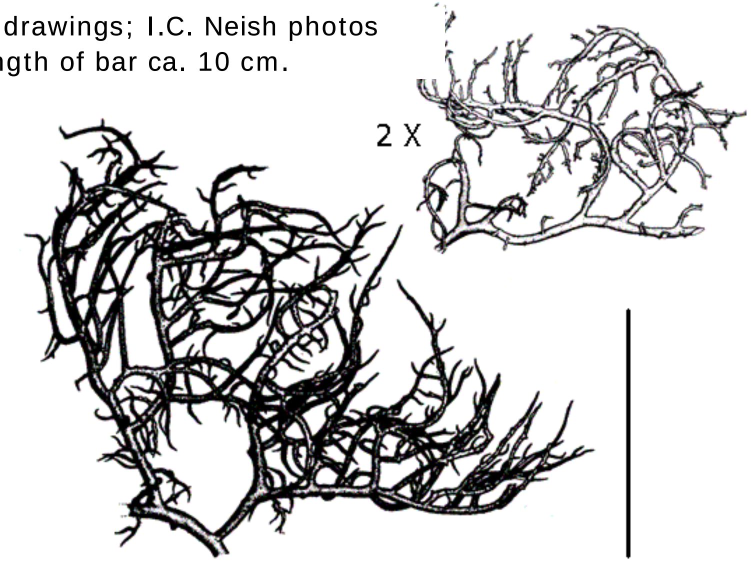
Plate 2-6. Flower type of cottonii. This may be found in several colour variants.

Plate 2-7. "Adik" (addict) type of cottonii - so called because the many gnarled branches and bumps on the thallus.

Plate 2-8. "Tambalang" type of Kappaphycus alvarezii as it appears in the vicinity of Zamboanga City in the Philippines.

Figure 2-5. Kappaphycus alvarezii var. tambalang plant (lower left) and closer view of branch (upper right) showing a cylindrical axis with branches commonly enlarged maximally just beyond the basal curvature toward the light as manifested through the "candelabra effect".

M.S. Doty drawings; I.C. Neish photos
Length of bar ca. 10 cm.



2.12. Varieties - Sacol cottonii, Betaphycus and Eucheuma

Kappaphycus sp. Sacol Island strain is one of several cultivars that has been propagated by vegetative propagation from plants obtained from wild stocks. Published data suggest that based on molecular analysis using the rbcL the Kappaphycus sp. 'Sacol' variety is most likely a form of K. cottonii (Aquilan *et al,* 2003) but some investigators believe it to be K. striatum.

Figure 2-6. Kappaphycus sp. Sacol Island strain (M.S. Doty drawing - Length of bar ca. 10 cm. relative to image).

The carrageenan from Betaphycus (gelatinae of the trade) is of commercial interest and is rather close to agar and furcellaran in its application performance. These small plants are awkward to handle and grow slowly when conventional eucheuma seaplant cultivation methods are used so Betaphycus farming has not yet achieved significant commercial proportions. Some has been cultivated in China both on monolines and by attaching propagules to stones or coral using string or elastic bands. Betaphycus gelatinum is cultivated and/or harvested from wild stocks to a much lesser extent that Kappaphycus or Eucheuma. It is the smallest of the eucheuma seaplants and inhabits sites with active water motion. Fronds are apically flat, pliable and arising from marginal cylindrical teeth.

Plate 2-9. Betaphycus gelatinum.

Eucheuma denticulatum (spinosum of the trade) is less variable than Kappaphycus. Several indigenous varieties have been developed from local wild stocks in the Philippines, Indonesia and Tanzania. There has been some dispersal of these stocks; notably from Bali to the Central Philippines. Eucheuma denticulatum plants generally appear as shown in Plate 2-10 except that the color may vary from light brown to deep red (almost black). Branches may be more or less spindly and the density of "spines" may range from sparse to dense.

One distinguishing characteristic of E. denticulatum is a distinct "chlorine-like" (probably bromine) odor that becomes especially noticeable during drying.

Plate 2-10. Eucheuma denticulatum. Drawing I.C. Neish after M.S. Doty; Length of bar ca. 10 cm. relative to image.)

3.1. Elements of seaplant growth in seashore habitats

Agronomic methods must be developed with a clear understanding of what seaplants need in order to grow well and produce profitable yields. Plants differ from animals in aquaculture systems and among seashore habitats in these important ways:

1. They get all their nutrients from the seawater that moves past them.

2. They must absorb photons in order to photosynthesize and grow.

3 They utilize carbon dioxide and generate oxygen; the opposite of animals.

4. Nitrogen compounds of the type excreted by animals are crucial nutrients to seaweeds

5. Unlike mobile animals such as fish, seaplants have no means of suspending themselves in the water column.

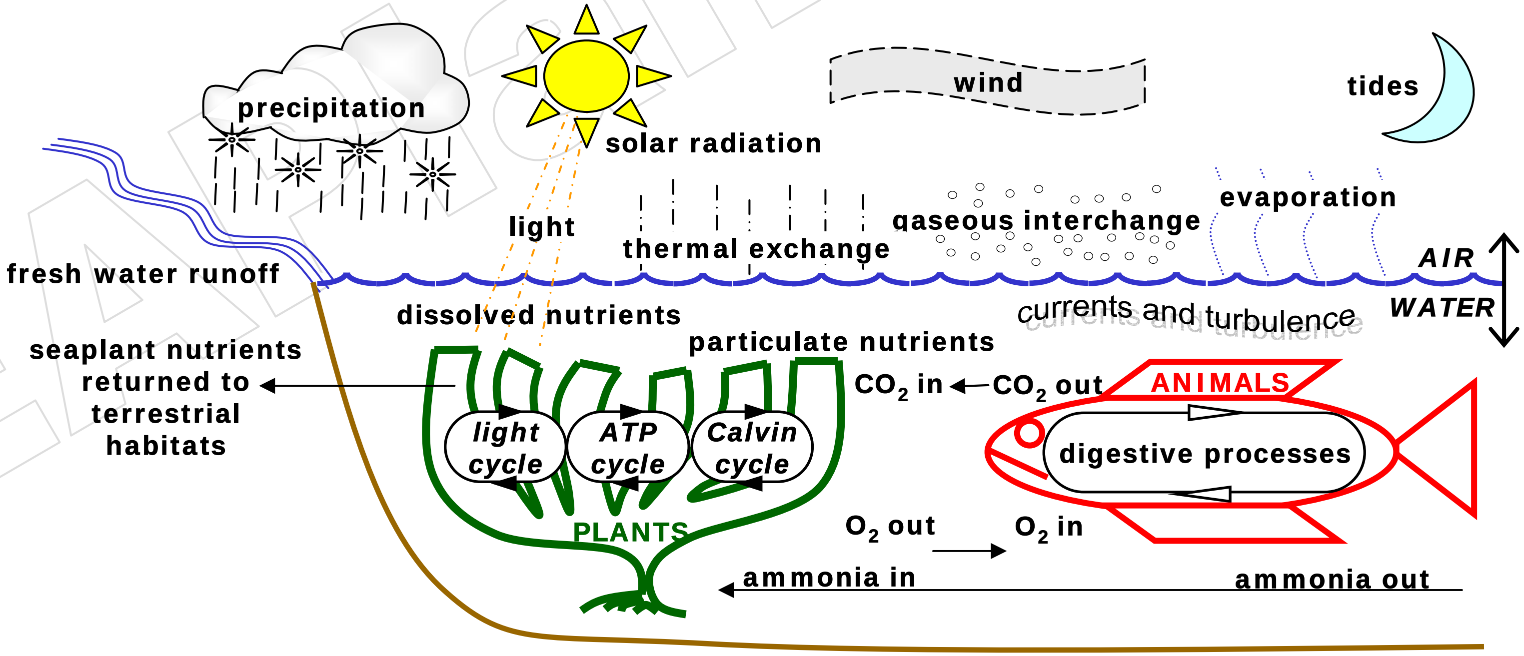
These factors have important implications for the types of culture system that must be used for raising seaplants including:

1. Enclosures or suspension systems must expose the plants to both light and water flow so volume-to-surface enclosures such as most fish cages are not optimal.

2. Plants must be separated and suspended by the use of physical structures (e.g. attachment to ropes) and/or applied force (e.g. air and paddle-wheel agitation).

3. Plants and animals can be combined in properly designed integrated systems to their mutual benefit.

Figure 3.1. Seaplants perform functions that result in the delivery of ecosystem services. Their metabolic processes utilize energy, materials, water, nutrients and gases to produce biomass and metabolites that impact on other organisms. This occurs in natural systems; in aquaculture systems; and in combined systems.



Click to table of contents

3.2. Seaplants in integrated multi-trophic aquaculture (IMTA)

Although plants and animals require different sets of culture conditions their requirements can be complementary. Seaplants and sea animals can be combined in integrated multi-trophic aquaculture (IMTA) systems as sown in Figure 3.2. Opportunities for eucheuma seaplants are discussed in more detail in *"Tropical Red Seaweeds as a Foundation for Integrated Multi-trophic Aquaculture (IMTA): Four propositions and an action plan for this major opportunity in the Coral Triangle"* (SEAPlant.net Monograph no. HB2E 1008 V1)

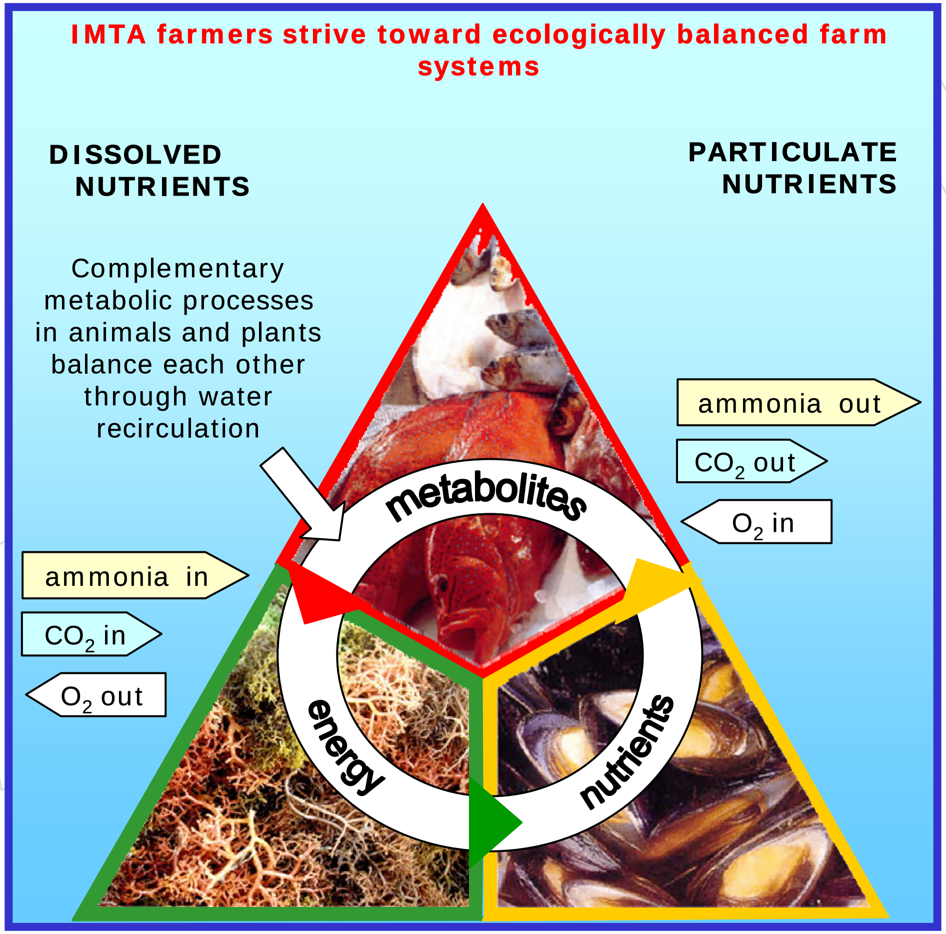
Figure 3-2. IMTA schematic

Seaplants use solar energy to photosynthesize
•
Restore water quality
•
Recycle nutrients
•
Produce marketable biomass

EXTRACTIVE PLANTS
(PHOTOAUTOTROPHS)

Plankton: microalgae, bacteria, protozoa

Macrophytes: macroalgae, vascular plants



FED ANIMALS
(HETEROTROPHS)

Omnivores: fish, crustaceans, holothurians

Carnivores: fish, shrimp, crabs

EXTRACTIVE ANIMALS
(HETEROTROPHS & PHOTOSYMBIONTS)

Symbiotics: corals, giant clams

Planktivores: fish, shellfish, zooplankton

Herbivores: fish, abalone, sea urchins

For IMTA to be sustainable it is essential to use seaplant biomass directly as feed and also as feed to produce extractive animals that can replace fish meal in carnivore diets

3.3. Water motion and seaplant growth

It has generally been noted that eucheuma seaplants grow best in moving water. Water motion helps to clean plants, bring fresh nutrients, remove metabolites and apply hydraulic forces that stimulate plant growth. Within the physical breakage limits of propagules and equipment one can approximate that faster water flow equals faster growth. In rapidly flowing water Kappaphycus plants can grow as much as two meters long and with major branches more than two centimeters across.

Effects of water motion are confounded with those of temperature, light and nutrients. Effects of the sun and the moon influence the water motion so important to seaplant growth. In the field both moon-driven tides and currents generated as a result of solar heating provide water motion. The sun's heat causes both wind (hence waves) and oceanic currents. When the water is deepest (e.g., at high tide) flow tends to be laminar. At the lowest low tides water motion tends to be turbulent. Turbulent water enhances inward and outward diffusion and minimizes the thickness of unmixed boundary layers. Water motion can also play an important role in "seeding" natural populations of eucheuma seaplants (Azanza-Corrales *et al.* 1996)

Eucheuma seaplants generally grow on algal reef flats and tidal movements are important in structuring their habitats. As the tides periodically subside desiccation occurs and the sun's radiation results in a decapitation of biological reef growths. This leaves level reef flats near the extreme low water mark. This combination of causes results in the flat, non-consolidated, relatively level and uniform environments where eucheuma seaplants tend to grow in the wild.

One certainty is that plant tissue will die if it is out of the water too long! Lines must be sunk deeply enough that tips do not extend above the water and die.

Plate 3-1. Desiccated tips die and turn white.

One important factor concerning water motion effects is the unmixed boundary layer that is caused by friction between the thallus and surrounding waters. The thickness of this layer is inversely proportional to water movement and turbulent flow disrupts the boundary layer. Still water can expose plants to low nutrient availability and high waste levels.

Figure 3-3. In very still water plants may consume the nutrients in immediately adjacent water and commence to "starve. The plants' waste products (metabolites) may also accumulate in unmixed layer and "poison" the plant.

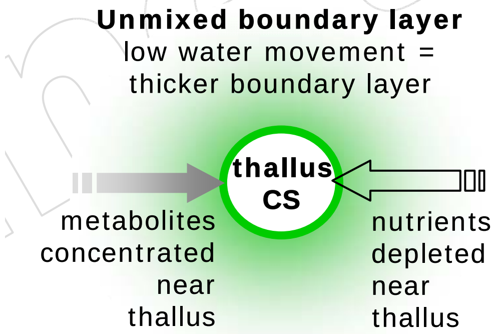


Plate 3-2. Combined effects of starvation and metabolite accumulation may cause "ice-ice" (right).

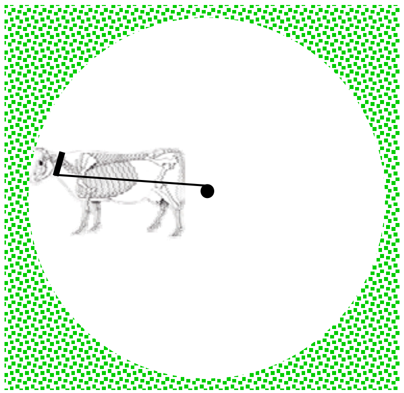


Figure 3-4. The "starvation" effect of very still water can be compared to what happens if you tether your cow using a short rope and then neglect to move her to another place.

Once she eats all the grass she can reach she will starve.

Water motion is a critical factor to take into account during the selection of farm sites and during crop logging.

3.4. Temperature and seaplant growth

Temperature can directly effect the physiological processes of eucheuma seaplants or it may indirectly effect plants by temperature impacts on the surrounding environment. For example temperature impacts water motion by generating wind, waves and currents.

Table 3-1. Glenn & Doty (1981) found physiological maxima for photosynthesis at 25°C for three species and they also observed that respiration increased 50-60% from 15°C to 20°C. Auto-oxidation increased sharply from 25°C to 40°C.

Species	**Max / range in ° C**	**Author or source**
K. Alvarezii	22.8 - 29.2	Ohno & Orosco (1987).
E. Amakusaensis	18 - 25	Ohmi & Shinmura (1976).
E. Denticulatum	Max. 34	Dawes (1979).
E. Isiforme	Max.18-25	Mathieson & Dawes (1974)
K. striatum	20 to 30 22.8-29.2	Mairh *et al.* (1986) Ohmi & Orosco (1987).
E. uncinatum	Max. 24	Dawes (1979).

Dawes (1979) reported that when thalli were returned to a standard 25°C after maxima were tolerated the values previously obtained at 25°C were not repeated consistently. He interpreted this as evidence of tissue damage at high temperature.

In Southeast Asian farm areas sea temperatures do not often reach critical levels but optimum ranges have been observed. Although farmers report rapid growth and high biomass production by Kappaphycus during months characterized by water temperatures ranging between 25°C and 30°C (Barraca, *pers. comm.*). Njoman et al. (1987) found temperatures of 27 to 32°C where they were rearing *K. alvarezii* on the south-western shore of Sumatra. Ohno & Orosco (1987).

Figure 3-4. The general temperature response of anabolic processes such as photosynthesis and growth is shown below. Anabolic processes increase until an optimal plateau is reached around 20ºC and growth declines again if the optimal temperature range is exceeded. If temperatures get too high plant tissue will die.

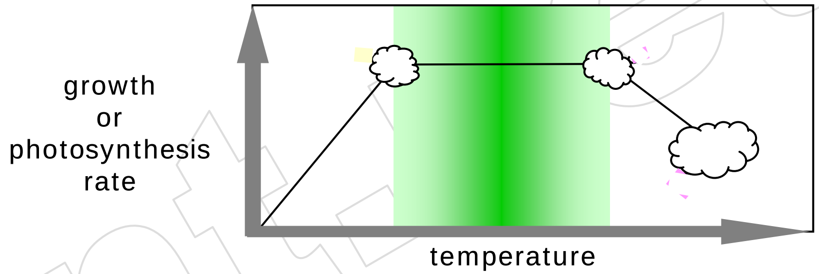
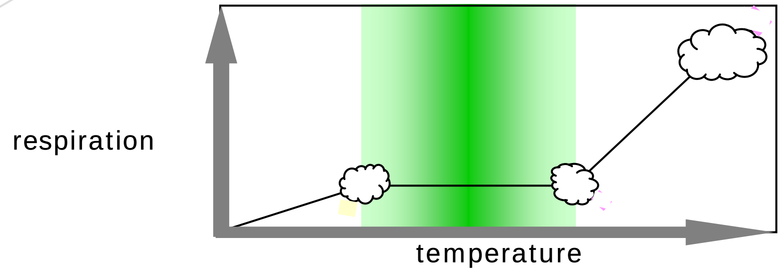


Figure 3-5. The general temperature response of catabolic processes such respiration is as shown below. Catabolic processes increase until a plateau is reached around 20ºC and increase again if the tolerable temperature range is exceeded. If temperatures get too high plant tissue will be consumed by respiratory processes and it will die.



In higher and lower latitudes eucheuma seaplants may be sensitive to seasonal cold and may even disappear during winter. For example the strong seasonality of E. uncinatum is well known. This species is confined to the Gulf of California. It appears in spring and dies off during summer in response to temperatures that exhibit wide seasonal variation. Ohno & Orosco (1987) and Mairh *et al.* (1986) reported on Kappaphycus striatum transferred in 1983 to Tosa Bay, Japan from the central Philippines. In November, when temperatures fell below 20°C, they found that the plants died.

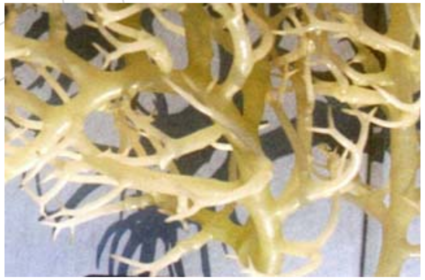
3.5. Light and seaplant growth

Exposure to optimal amounts and wavelengths of photosynthetically active radiation (PAR) is probably as essential for eucheuma seaplants as it is for other plants. Mairh (1986) found that with K. striatum maximum growth rates were obtained with a 12:12 L:D cycle at 6,000 lx. but growth rates started to drop above about 10,000 lx. Dawes (1979) reported that growth rates increased to about 18,000 mW cm-2 of white light for *E. denticulatum*, E. isiforme and E. uncinatum. Eucheuma appears to have a daily photosynthetic rhythm both for photosynthesis and respiration, (Glenn & Doty 1981). It appears that Eucheuma and Kappaphycus are opportunistic with respect to photosynthetic responses to light.

Photosynthesis in Kappaphycus shows a diurnal pattern with a peak in late morning. Glenn & Doty (1981) observed that storage conditions could effect such periodicity. During storage trials there was strong periodicity from the thalli stored overnight outdoors and strong suppression of periodicity in thalli stored indoors.

Excessive light can have deleterious effects on growth of eucheuma seaplants. This has been attributed to excessive light in respect to other elements in the environment. In non-tidal situations such as on floating rafts or in shallow ponds; or in sites with high reflectance from white sandy bottoms sudden crop death has been noted and this seemed be light-related. In early farming days Doty noted (*pers. comm.*) that by June 22 secondary branchlets of K. striatum turned away from the light and by late May or June many thalli died on the shallow reef flats then in use. These could be offset by moving thalli to bottoms of greater water depth. Zertuche et al. (1987) obtained best growth by shading culture tanks to achieve light intensities measured where the thalli were collected in the wild.

Plate 3-3. Severe bleaching in a plant growing in a high light, low water flow environment (India, 2002).



Eucheuma seaplants are generally grown in suspended culture within one meter of the sea surface or on structures attached to the sea floor where water depth is about one meter during average low tides. On some farms the adverse effects of intensive sunlight near the sea surface can be offset by intensive planting such that distances between lines and cuttings are close enough to permit shading (e.g. Trono, 1994). Another method that works is to move plantings to a greater depth.

When farmers succeed in placing plants close to optimal conditions eucheuma seaplants exhibit a growth habit sometimes referred to as a "candelabra effect" (plate 3-4). Plants are very clean, have even pigmentation and have profuse branches distinctly growing toward the light.

Plate 3-4. The "candelabra effect". (Flores, Indonesia, 2004).

There may be differences among eucheuma seaplant strains with respect to photosynthetic responses. Dawes (1992) found that different color variants of K. alvarezii and E. denticulatum exhibited different responses. Color responses may be effected by the abundance of nitrogen storage compounds in plants since many are present in the form of nitrogen-based pigments.

As a general rule it appears that the darker the plant, the more stored nitrogen it contains. A single plant may exhibit a range of color spanning from very pale yellow to very dark brown or green over the course of several weeks and this can be expected to have an impact on photosynthetic responses.

3.6. Salinity and water quality

The effects of nutrition and salinity on Kappaphycus are not well known although it can be assumed that they are of critical importance to plant growth. Kappaphycus seems to grow best in "full salinity" seawater. At most successful farm sites salinity seems to be on the order of 30-35 ppt. Dawes (1979) found E. isiforme to have a broad respirometric maximum at about 30-40 ppt. Both E. uncinatum and E. denticulatum had maxima near 30.ppt.

Salinity and terrestrial influences are significant for seaplants in both negative and positive ways. Seawater strongly influenced by land is significantly different in salinity and micronutrient content from pristine open-ocean water such as that which usually bathes wild eucheuma seaplant populations (Table 3-2).

Water from wells and near-shore areas has a high silica content but it may be 0.1 ųg-atm l or less in ocean water. Note the wide variation in both fixed nitrogen and phosphate values and the ratios between them (Table 3-2).

Though it has not been possible to date to obtain analyses of the water surrounding wild eucheuma seaplants populations they probably receive water near the lowest silica values such as the oceanic surface water shown (Lines 11 and 12; Table 3-2).

Glenn and Doty's (1990) 55-week study in Hawaii utilized Coconut Island North Reef water in the field (Line 8; Table 3-2). In laboratory work they usually used either Natatorium Reef (Line 10; Table 3-2) or Anuenue Fisheries Research Center water (Line 1; Table 3-2). Best growth of Eucheuma spores was in such water or in water from Kaneohe Bay (Lines 4 & 8; Table 3-2). The shallow ponds mentioned above under "Light" had Coconut Island water flowing into them (Line 7; Table 3-2).

In water favorable to other seaplants some Eucheuma species such as E. denticulatum may die. In Anuenue water (Line 1; Table 3-2) E. denticulatum always died quickly and disappeared, as did E. isiforme when out-planted in water from Kaneohe Bay (Line 8; Table 3-2). In terrestrially contaminated well waters K. striatum lingered on and K. alvarezii grew at about half its usual rate.

Table 3-2. Nutrient analyses of Hawaiian waters with ocean surface values for comparison (ųg-atm l). Codes: "D" (dipped), "P" (pumped from bay or shore), "W" (pumped from wells) or, in reference to Keahole Point water provided by the National Energy Laboratory Hawaii, "S" (shallow, warm) or "C" (deep, cold). (Doty et al. 1986).

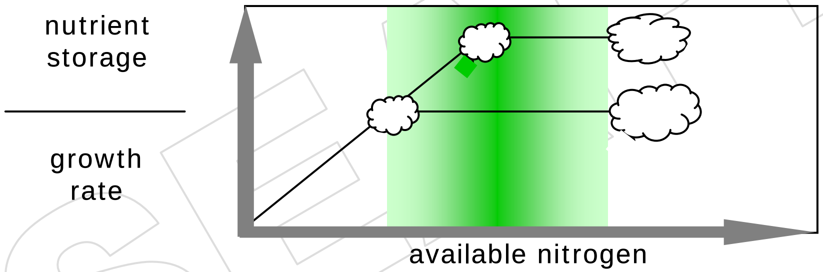
	Salinity	PO_4	NO_2 / NO_3	NH_4	Si
1- Anuenue Fish. Res. Ctr. "W"	-	1.1	15.9	36.0	193.7
2- Aurea Marine Inc., Kahuku "W"	24 ppt.	1.7	7.8	64.6	178.7
3- MRTC pond Kaneohe Bay "P"	15 ppt.	3.2	23.4	4.2	45.1
4- Lilipuna Pier, Kaneohe Bay "D"	34 ppt.	0.1	0.1	2.1	28.7
5- Waiahole stream water "D"	1 ppt.	0.1	0	0	27.8
6- Waiahole + Wahiawa soil	5 ppt.	0.3	1.3	0.1	23.5
7- Coconut Is., Kaneohe Bay "P"	32 ppt.	18.5	0.7	0.9	6.0
8- North reef of same Island "D"	34 ppt.	0.1	0.2	1.4	5.6
9- Keahole warm NELH 20 m "S"	-	0.2	0.2	0.4	3.0
10- Natatorium reef Waikiki"D"	-	0.1	0.1	0.1	1.9
11- Keahole cold NELH 610m "C"	-	3.0	39.0	0.2	0.2
12- Ocean surface	-	<2.9	1-50	<5-50	<0.7-1.8

Among macronutrients it seems generally accepted that nitrogen is crucial for productive farming and can be a limiting factor in sea cultures. In Hawaii macronutrient conditions were measured upstream and downstream of an unusually dense planting of eucheuma seaplants (Glenn & Doty, 1990; Table 3-3). The results indicated utilization of phosphates, nitrate and nitrite and production of ammonium nitrogen as water flowed through the plantings. The net production of ammonia was attributed to resident grazer populations.

Table 3-3. Results from Glenn & Doty (1990)

Sample site	Water motion	NH_3-N	NO_3+ NO_2-N	PO_4-P	O_2
Upstream	45	1.98	1.44	0.66	7.22
Downstream	38	2.01	1.10	0.62	8.25

Figure 3-6. The general response of eucheuma seaplants to macronutrients such as nitrogen is believed to follow the pattern shown below. Growth and nitrogen storage both increase in the presence of nitrogen until storage capacity is full. After that growth and nitrogen uptake remain at a plateau.



Pending further work with eucheuma seaplants one can postulate that they have nitrogen metabolism fundamentally similar to that of Chondrus. Neish and Shacklock (1971) found that holding Chondrus crispus in conditions of high light and low nitrogen led to an upward shift in the carbon/nitrogen ratio of the tissues, a higher yield of kappa-carrageenan and higher gel-strength extracts.

It appears that this "ripening" phenomenon (also called the "Neish effect" after Arthur C. Neish) may be related to macronutrient storage; in particular to nitrogen storage. This has not yet been demonstrated convincingly in eucheuma seaplants but a bleaching phenomenon similar to the "Neish Effect" is observed among eucheuma seaplants (Plate 3-5). Thus far, however, adequate coupled laboratory activity is not known. Zertuche-Gonzales *et al.* (1993) showed that higher carrageenan yields were obtained from cultures with fertilized E. uncinatum under high light conditions.

Plate 3-5. The photo below shows K. alvarezii plants from same-source propagules grown at different locations on the same farm at the same time. The white plants were from a low water-flow area and had lost almost all pigmentation. (India, 2003)

Various unpublished experiments on nutrient fertilization have been carried out under farm conditions. Under such circumstances there may be a huge number of water changes each day and usually very little effect of the fertilization is seen even when the fertilizer is slowly disseminated from a porous container (Doty, unpublished). However Mairh *et al.* (1986) and others have had good growth and maintenance of stocks for a several years using various formulations of artificial seawater and various micronutrient mixtures.

fertilization has never become widespread among eucheuma seaplants farmers; probably because of high fertilizer cost and high losses of fertilizer through diffusion when they apply it to sea cultures.

3.8. Micronutrients and metabolites

Little is understood about the micronutrient requirements of eucheuma seaplants but these plants are clearly capable of assimilating and storing a wide range of elements including heavy metals and pesticide residues.

The tendency for eucheuma seaplants to concentrate heavy metals and pesticide residues means that care must be taken in site selection. It is prudent to check the level of concentration that is occurring in order to avoid places where unacceptable levels may be reached.

During their studies of eucheuma seaplants growth in Hawaii Glenn and Doty (1990) noted that the micronutrient content of well waters ran from 50 to 100 times those of open coastal water and included a large amount of silica and iron. Some eucheuma seaplant species died and others thrived in waters whose silicate content is accepted as being indicative of strong igneous terrestrial influence (Lines 1 and 2, Table 3-2). Silicon *per se* probably has little direct influence on seaplants but it is associated with other elements that may effect them. Also, silicate favors diatoms which can be pests in eucheuma seaplant cultures.

Doty and others have published various reports inferring nutrient effects from the observed growth habits of plants on farms and in test plots. For example during early stages of farming in the Philippines floating cultures of Kappaphycus were repeatedly tried unsuccessfully and it was eventually concluded that something essential to growth was needed from materials generated near the sea bottom. This hypothesis was derived from results obtained in experiments in which plants were alternated between bottom and surface rafting (Doty, 1971b).

In the northern Philippines Doty found that thalli grew poorly over deep water but well where they were in contact with algal reef flats. For some years planting was done only on extensive algal reef flats. At the time of initial plantings (early 1970s) there were no facilities for sampling and analysis that would enable eucheuma seaplant agronomists to learn what the bottom material contributed.

Despite early negative experiences in the Philippines rafting and longline systems near the sea surface have become widely accepted as suitable methods in most countries where eucheuma seaplants are farmed. Cultivation near the sea surface works best in protected areas where seawater is very well mixed. This occurs in areas where strong tidal currents are found coursing through narrow, protected channels in proximity to deep-water areas

Plate 3-8. Vigorously growing Kappaphycus from a choice farm site (right, Flores, Indonesia, 2004).

Plate 3-9. Good farming conditions are often found at locations near barrier reefs where seawater courses tidally into farm areas yet farm structures are protected from heavy wave action. (e.g. Bali, below).

One can presume that Kappaphycus produces metabolic waste products that are excreted from the thallus and must be diffused away from the plant. Kappaphycus spp. and Eucheuma spp. both exude a slight odor that intensifies on drying; especially in the case of Eucheuma. The odor is reminiscent of chlorine and may be associated with the brominated phenolic compounds that have been found in seaweeds. It has been speculated that such metabolites play a role in protecting plants from grazers.

The fundamental basis of seaplant agronomics is that a farmer works with other people to create habitats suitable for the desired crops within natural environments.

Figure 4-1. Elements and functions of seaplant agronomics systems are shown below and are further described in Table 4-1 opposite.

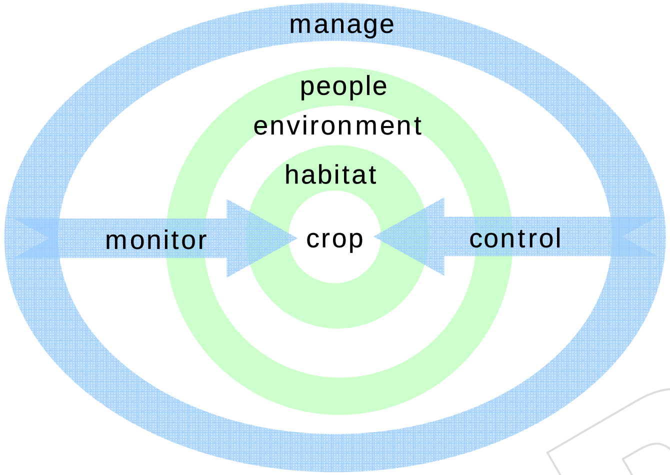


Plate 4-1. Farmers monitor the status and behavior of fundamental agronomic elements and then, to the best of their ability, they manage and control the farm system to profitably produce saleable crops. (Pulau Nain, Sulawesi Utara, Indonesia, 2004)

Table 4-1. Elements and functions of seaplant agronomics.

Elements

People… The social environment in which a seaplant enterprise undertakes functions including stakeholders such as , employees, suppliers, buyers and government agents.

Environment… Interactions with the physical environments of seaplant farms - especially minimization of adverse impacts

Habitat… Development, construction and operation of the physical structures that comprise seaplant farms.

Crop… The population of eucheuma seaplants that comprise farm populations and yield the crop.

Monitoring functions

People… Maintaining useful interaction with stakeholders

Environment… Measurement, recording and data handling for meteorological and oceanographic parameters

Habitat… Oversight and inspection leading to preventative maintenance of farm structures and equipment

Crop… Logging

Control functions

People… Standard personnel management and business management for small-medium farm enterprises

Environment… Pro-active minimization of negative environmental impacts and maximization of positive impacts

Habitat… Operation of farm structures and equipment through manually applied operational protocols and automated control systems

Crop… Planting, maintenance, harvesting and post-harvest treatment (PHT) of the crop

Attachment methods initially used were the "tie-tie" method and containment in bags. "Loops" have replaced "ties" in some places over the past 20 years; especially in Indonesia.

Plate 4-2. Loop systems have the advantages of reducing planting labor, easing the recycling of planting materials and eliminating most raffia or string from the crop.

short loop

long loop

Bag methods protect crops but they are expensive so their use tends to be confined to propagule production. The major habitat configurations that developed for commercial use have been "floating" and "off-bottom" systems. Floating methods employ stakes, rafts or floats to suspend lines near the sea surface. Off-bottom methods utilise stakes driven into the sea floor to suspend lines above the sea floor.

Advantages of floating systems include:

1. Grazing by bottom associated animals is minimized or eliminated because the plants are out of reach for benthic grazers.
2. Plants near the surface of the water column are generally exposed to water movement (e.g. wave chop).
3. Floating cultures can be tended during any tide level whereas work on off-bottom cultures is limited by tidal cycles.
4. Floating cultures are not restricted to shallow waters.

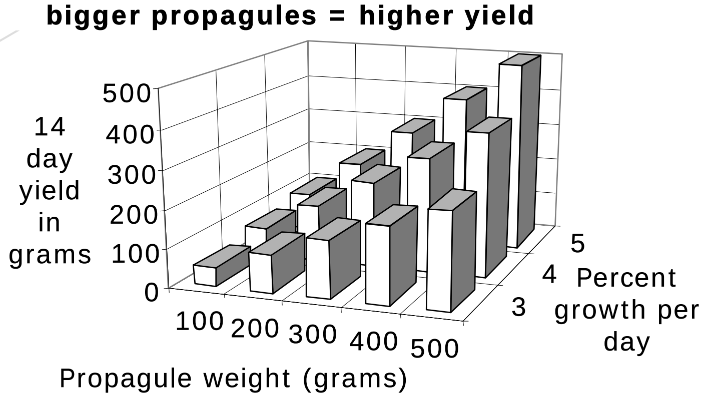
A wide variety of line arrays can be seen in commercial farms. Efficacy of habitat construction and technique is primarily dictated by environmental factors but in some cases it seems to be a matter of farmers' experience or preference.

Once cultivar strains have been selected the key elements of propagule management are as follows:

1. Choice of cultivar strain (s) to be grown.
2. Size of propagules to be planted.
3. Age and/or size at which propagules are to be harvested.
4. Spacing of propagules on and within habitat systems.
5. Selection and cutting of propagules for replanting

Large propagules generally yield higher farm productivity than small propagules. Practical limits to propagule size depend on local conditions. Usually breakage loss due to water motion is the main limiting factor.

Figure 4-2. The relationship of crop yield to propagule weight and growth rate.



There is wide variation among farm areas with respect to propagule size at planting and harvesting. Age at harvesting is most commonly set at 40-50 days. Significantly longer and shorter cycles are encountered in some regions. In some areas "pruning" is done as propagules are left attached to lines for many weeks and growing tips are removed. This method may cause quality problems related to an unfavorable mix of young and old tissue in the crop and it is discouraged by some buyers.

4.3. Managing propagules - spacing & harvest cycles

With respect to the combined effects of propagule size and cropping cycle two distinctly different strategies have been evolved by eucheuma seaplant farmers:

1. Small size - Long cycle with propagules of about 50 - 150 grams cropped at 45-60 day cycles.

2. Large size - Medium cycle with propagules of about 150-300 grams cropped at 30-45 day cycles.

Strategy choices are determined by a combination of local conditions and farmers' opinions. Generally choppy waters tend to favor "Small-Long" strategies but smooth waters with strong currents favor "Large-Medium" approaches. In all cases a major determining factor in strategy choice is the point at which significant propagule breakage-losses take place.

Spacing of propagules varies widely among farm regions. Generally farmers adopting Small-Long strategies tend to space propagules close together on lines (10-20 cm.) while those adopting Large-Medium strategies space plants more widely on lines (20-30 cm.). Spacing between lines follows a similar trend with the space between lines often being similar to the spacing of plants on lines. This depends partly on space availability, habitat type and currents. Some longline methods involve the spacing of lines several metres apart as a means of reducing line tangling.

Selection of clean, vigorous growing tips for replanting is an essential function of farm management; propagules must be securely attached but not too tightly bound. Generally propagules are broken from their mother plants by transverse cuts or breaks. Trono and Ganzon-Fortes (1989) proposed that slicing plants obliquely yields higher growth rates than transverse cutting. Apical tissue grows faster than basal and median fragments (Mairh *et al*., 1995). Well branched, obliquely sliced propagules with numerous tips appear to be best for replanting.

A superficial examination of eucheuma seaplant farming can mislead the observer into thinking that it is a low-effort occupation in which farmers simply tie cuttings to strings, go away and return to harvest the crop after 5-6 weeks. Nothing can be further from the truth. Seaplant farming is an occupation such that the most successful are those with skill, diligence and a "green thumb". This means “Tender, Loving Care" (TLC).

The best fertilizer is a farmer’s reflection on the water…
this an enduring principle of seaplant agronomics.

Plate 4-3. Pulau Nain, Sulawesi Utara, 2004

TLC means daily attention to functions such as:

1. replacing loose or weak propagules;
2. shaking silt or other loose "scum" off the plants;
3. removing drift material such as plastic bags, debris and weeds that get tangled in the crop;
4. re-attaching or tightening detached or loose lines;
5. replacing or repairing loose netting, stakes, floats, etc.

Care for farm structures and crops is essential to success but it is equally important to take care of the surrounding environment. Farmers must take care to avoid trampling or damaging local habitats; littering the environment with trash; polluting farm areas with human and other waste; or undertaking destructive collateral activities such as fish bombing and over-harvesting mangroves.

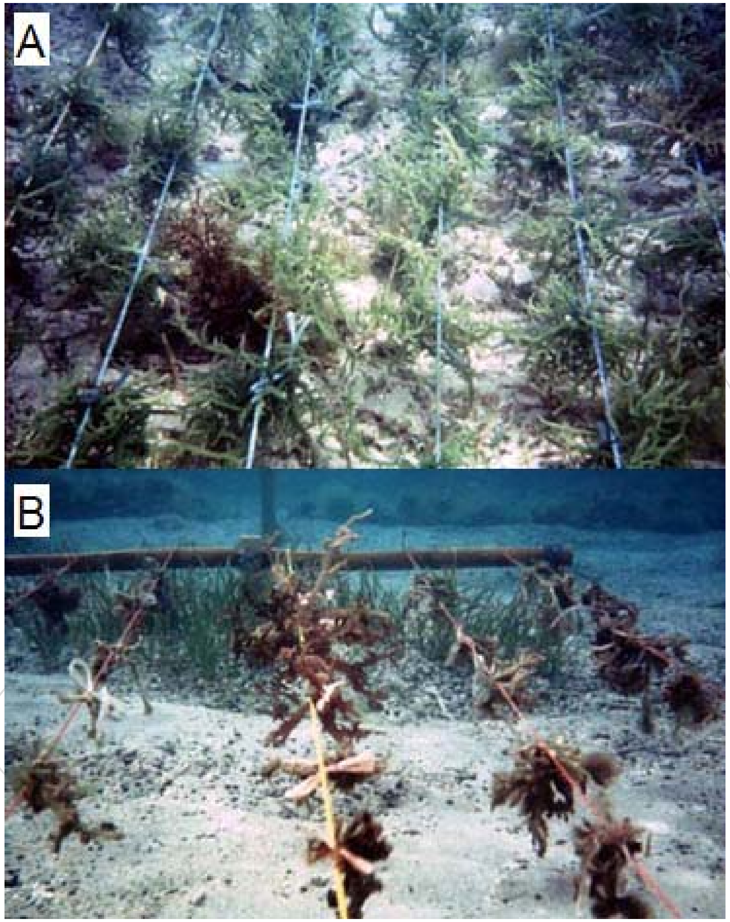
4.4. Managing propagules -Tender Loving Care (TLC)

Plate 4-4. TLC in action!

Farm "A" has been tended daily with TLC.

Farm "B" has been neglected.

These photos were taken at the same time in the same place. The farms were next to each other. They were using the same source of propagules and had been planted at the same time. (Bali ca. 1990).



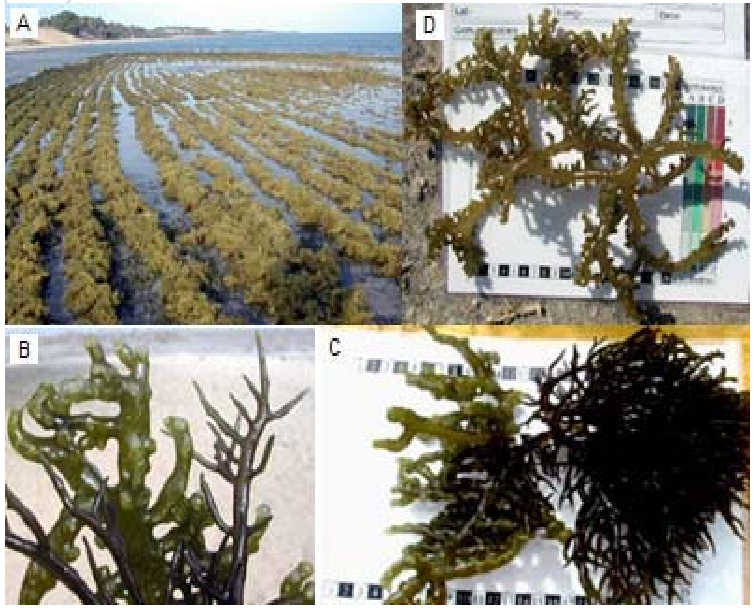
Regular crop monitoring programs should include the orderly maintenance of a database that includes crop logging forms and plenty of photographs for immediate and future reference.

Aerial photographs give the best overviews but farm photographs taken from the ground (e.g. Plate 4-5, below) can give an excellent picture of how crops are doing if they are complemented by closer shots.

Plate 4-5. "A picture is worth a thousand words" (A) - This is a truism never more appropriate than when applied to eucheuma seaplant crops.

It is useful to photograph plants at the extreme range of variation from a site both in close-up (B) and at the whole-plant level (C).

It is also useful to photograph specimens against a background with color index and scale (D).



4.5. Crop logging basics

With proper agronomic methods eucheuma seaplant farming can produce bountiful crops on a sustainable basis with minimal disruption to surrounding environments.

Seaplant agronomics is among the arts and sciences that conform to natural conditions... it is not a set of methods for "bending nature to your will".

Two "rules of thumb" comprise the most basic concepts of this approach:

1. Go with the flow of environmental conditions and minimize environmental disturbances.
2. Observe and learn from what the crop and associated organisms are doing. Learn how to interpret the "signals" that they are sending and plan actions accordingly.

Successful eucheuma seaplant farming requires that you "go with the flow" of seasonal events by:

1. Where possible, selecting several locations that permit seasonal shifts of farming effort among sites - a defining characteristic of eucheuma seaplant agronomics.
2. Designing farm equipment and agronomic protocols that facilitate flexibility in farm expansion, contraction and re-location.
3. **Implementing a crop-logging system** that enables timely tracking of seasonal changes and indicates appropriate action.

Crop-logging is a process of recording environmental variables and crop condition in a structured and methodical manner. Results are best saved in databases and data products can usefully be circulated to technical and management personnel. Good statistics should be kept for farm inputs and outputs. This is "macro-crop-logging" information that can give valuable insights into crop logging done at a more "micro" level.

Ideally sites should be monitored on a weekly basis. The crop-logging program should be augmented by use of properly stored and indexed digital photographs.

As experience is gained with seaplant crops it becomes rather easy to "read" what sort of condition they are in.

Plate 4-6. Even a beginner can probably rank the following plants in order of their well-being:

A good crop log database comprises valuable equity for any seaplant farming business.

Proper development and use of this information preserves experience and knowledge through successive generations of management and staff. Your hard-earned expertise does not simply "walk out the door" when people move on to other things or get pirated by your competition – and new recruits do not have to waste valuable resources by "reinventing the wheel". **Successful crop-logging involves vigilance and methodical data logging using three types of monitoring program:**

1. Keeping accurate records of planting, harvesting and growth rates (e.g. through use of test-lines and test-plots).
2. Measurement of oceanographic and meteorological parameters.
3. Monitoring of crop condition.

4.6. Crop condition indices - decision tree

Figure 4-3. A simple crop-index letter/color code can be generated for eucheuma seaplant crops using the decision tree shown below. Further explanation of these crop conditions is presented on the following pages.

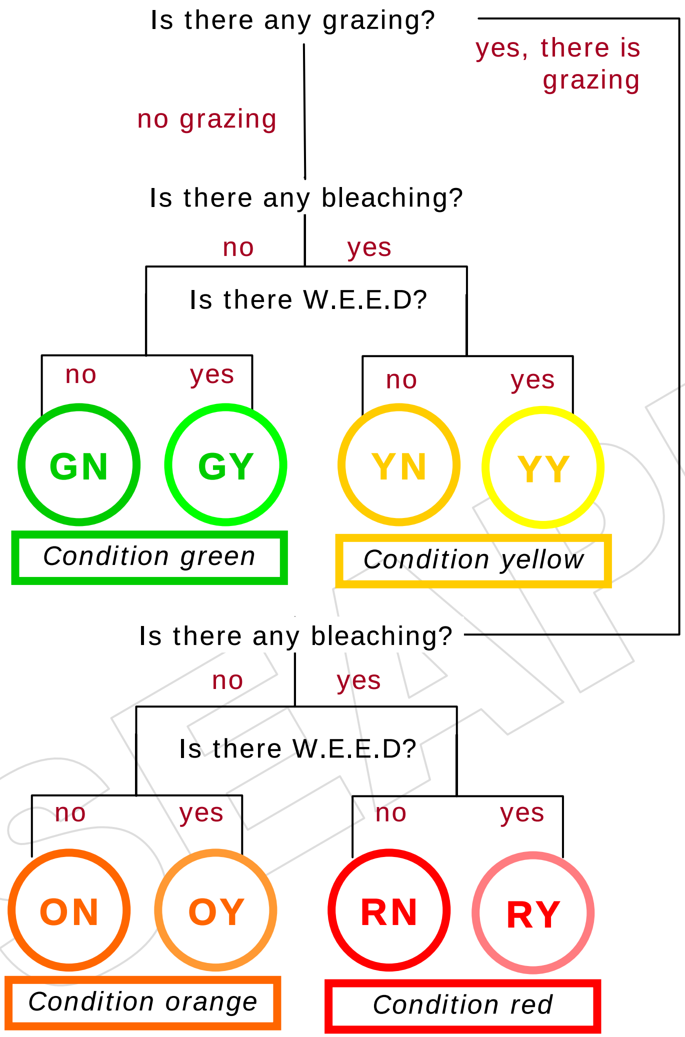


Figure 4-4. Action options in response to observed condition are:

1 — **ACTION GREEN = 1 = maximize**
Tend the crop industriously and take advantage of the good crop yields that come with "Condition Green". Plant vigorously. The ability to expand plantings during "Condition Green" will determine maximum attainable farm yields.

2 — **ACTION BLUE = 2 = MAINTAIN**
Tend the crop industriously and maintain vigilance to ensure that "condition yellow" is not emerging. Plant vigorously as long as signs of trouble are not worsening at a noticeable rate. Be ready to harvest as soon as there are signs of impending or rapidly developing trouble.

3 — **ACTION YELLOW = 3 = VIGILANCE**
Maintain frequent vigilance to see if conditions are getting worse. Replant with better propagules if possible. Adjust agronomic protocols. The crop is still doing OK but there are losses to grazers or noticeable W.E.E.D. problems that add to labor cost (e.g. having to pick out weeds) and/or reduce crop quality.

4 — **ACTION ORANGE = 4 = MOVE**
If possible move crop to better sites if growth is decreasing. Conditions can rapidly move toward an "Action Red" situation where significant crop losses may occur.

5 — **ACTION RED = 5 = BAIL OUT**
Move crop immediately to sites with better conditions or crop out farm. If conditions are such that "Action Red" is required that means significant crop losses are occurring.

Click to table of contents

4.7. Crop condition green & orange

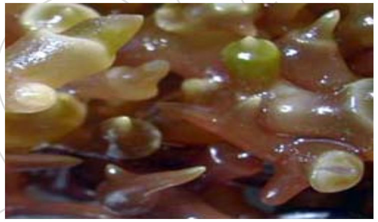
Figure 4-5. CONDITION GREEN; NO/LOW W.E.E.D. (GN)

Plants are healthy, with good color and no more than trace amounts of grazers or weeds, epiphytes, epizoa or disease (W.E.E.D.).

color Density	Grazing Level	W.E.E.D. Level	CONDITION INDEX	ACTION INDEX
low	trace or none		GN	2
medium-high				1

Figure 4-7. CONDITION ORANGE; NO/LOW W.E.E.D. (ON)

Plants are healthy, with good color but show signs of noticeable grazing. Significant grazing means significant yield losses. Severe grazing means that grazers are harvesting most of the crop.



color Density	Grazing Level	W.E.E.D. Level	CONDITION INDEX	ACTION INDEX
medium to high	noticeable	none or low	ON	3
	significant			4
	severe			5

Figure 4-6. CONDITION GREEN; YES TO W.E.E.D. (GY)

Plants have good color but if weeds, epiphytes, epizoa or disease W.E.E.D. become significant farm economics suffer. At "severe" levels it is time to crop out.

color Density	Grazing Level	W.E.E.D. Level	CONDITION INDEX	ACTION INDEX
medium to high	none or low	noticeable	GY	3
		significant		4
		severe		5

Figure 4-8.CONDITION ORANGE; YES TO W.E.E.D. (OY)

Plants are healthy, with good color but grazers and W.E.E.D. are taking over the farm.

color Density	Grazing Level	W.E.E.D. Level	CONDITION INDEX	ACTION INDEX
medium to high	noticeable		OY	4
	significant			5

Click to table of contents

4.8. Crop condition yellow & red

Figure 4-9. CONDITION YELLOW; NO/LOW W.E.E.D (YN)

Plants may appear to be healthy but have a very pale color. Growth slowing or negative. Essential nutrients depleted. “Ice-ice” symptoms likely.

Bleaching	Grazing Level	W.E.E.D. Level	CONDITION INDEX	ACTION INDEX
noticeable	none or low		YN	3
significant				4
severe				5

Figure 4-11. CONDITION RED; NO/LOW W.E.E.D (RN)

Plants show early symptoms of bleaching <u>and</u> show signs of noticeable grazing.

color Density	Grazing Level	W.E.E.D. Level	CONDITION INDEX	ACTION INDEX
noticeably bleached or worse	noticeable	none or low	RN	4
	significant			5

Figure 4-10. CONDITION YELLOW; YES TO W.E.E.D (YY)

Plants show early symptoms of bleaching <u>and</u> show signs **W**eeds, **E**piphytes, **E**pizoa or **D**isease (**W.E.E.D**).

color Density	Grazing Level	W.E.E.D. Level	CONDITION INDEX	ACTION INDEX
noticeably Bleached or worse	none or low	noticeable	YY	3
		significant		4
		severe		5

Figure 4-12. CONDITION RED; YES TO W.E.E.D (RY)

Plants show early symptoms of bleaching <u>and</u> show signs of noticeable grazing + W.E.E.D. You have all the problems here...

color Density	Grazing Level	W.E.E.D. Level	CONDITION INDEX	ACTION INDEX
noticeably bleached or worse	noticeable		RY	4
	significant			5

4.9. Monitoring the environment

Site selection and crop logging activities can only be effectively undertaken if a sound, complementary environmental monitoring program is maintained.

In many suitable seaplant farming areas a variety of institutions maintain environmental data bases that can be made available to seaplant farmers on reasonable terms. Data products of particular use for farm siting, planning and management include the following:

1. **Tide tables** available from government or international sources or from tide prediction programs that can be run on computers.
2. **Nautical charts, topographic charts, aerial photographs and satellite imagery.**
3. **Meteorological records** from nearby airports, government research stations or weather stations.
4. **Oceanographic records** from nearby government institutions or private factories and utilities.

Whether or not useful environmental data can be acquired from third parties it is almost always useful for seaplant farmers to undertake local monitoring programs whether individually, as groups or within government, NGO and privately sponsored programs. The most significant parameters to monitor are water motion, water temperature, wind speed, wind direction, rainfall, solar radiation, salinity and nutrients.

The measurements resulting from environmental monitoring can be stored in databases and used in correlation studies among crop-log data and environmental parameters. Most farmers do “crop logging” in their heads and do not maintain written records. This works well for the diligent farmer but it is not suitable for recording historical records and conveying information to others.

Some useful monitoring devices and methods are illustrated in Plate 4-7 opposite.

Measuring nutrients directly can be costly and tedious so by far the most effective way to track these is to utilize parameters such as the plant condition indices presented in Figures 4-3 to 4-12.

The speed and velocity of water currents can be measured using a variety of devices but Doty (1971) devised a "clod card" system that attaches uniformly-made, appropriately-designed masses of calcium sulphate to wing-like cards. This enables comparison of total water movement among a variety of habitats. Diffusion of calcium sulfate, which is only slightly soluble, provides a measure of water movement that approximates conditions encountered by living seaplants.

Plate 4-7. Salinity checks can be done using a hand-held refractometer (A). Sunlight can be monitored using the classic Campbell Stokes heliograph (B) or transducer/data logger combinations such as the Kipp & Zonen (C). Wind speed and direction can be recorded using instruments available from several suppliers (D). Temperature records can be maintained on the basis of measurements made using simple minimum-maximum thermometers (E).

Manufacturers’ photos

4.10. Crop logging reports

Table 4-2. The form illustrated below is an example of the type that can be used during the development of crop log databases. The precise arrangement of fields and the scope of data to be collected may vary among locations.

Weekly Crop-log Form

Site name: Crop:
Week No. Date Observer
Site latitude:
Site longitude:
Crop scale/action at week start at week end
Km. total line: Km. planted:
Km. harvested: Tons harvested:
Photo index Nos. /notes

Clod card starting gms. Ending gms.

	Sun	Mon	Tue	Wed	Thu	Fri
Minimax Temperature ºC						
Rain mm.						
Wind direction						
Wind speed (m/sec)						

Notes about Weeds, Epiphytes, Epizoa & Disease (W.E.E.D.):

\+ = noticeable ++ = significant +++ = severe

		comments
Weeds (WE)		
Epiphytes (EP)		
Epizoa (EZ)		
Ice-ice (II)		
Other diseases (OD)		

Table 4-3. Besides obtaining reports from regular crop logging stations farm developers and crop-logging institutions such as SEAPlant.net need to acquire data from spot checks of sites throughout tropical seaplant growing regions. Hypothetical examples of the same report in written form and as a mobile-phone text message are shown below:

Site inspection Form

Reporter: Nyoman Antara Crop: cottonii
Site name: Desa Indah Date: 01/08/04
Site latitude: 2.30.30
Site longitude: 117.40.50
Crop scale & action: ON 3
Km. planted: 250
Typical monthly harvest (mt): 10
Photo index Nos. /notes: 23 photos (DI 010804 1-23)

Notes on grazing (if any): slight tip-nipping

Notes about Weeds, Epiphytes, Epizoa & Disease (W.E.E.D.):

\+ = noticeable ++ = significant +++ = severe

		comments
Weeds (WE)	+	traces of Ulva
Epiphytes (EP)		
Epizoa (EZ)	+	some bryozoa on older tissue
Ice-ice (II)		
Other diseases (OD)		

According to this report Desa Indah is exhibiting condition Orange with traces of Ulva, slight bryozoan infestation and noticeable grazing by "tip-nippers" such as rabbitfish so vigilance (Action Yellow-3) is required. There is about 250 km of planted line said to be yielding about ten tons of dry cottonii per month. 23 photos were taken and the index numbers are indicated.

Desa Indah cott
2.30.30 & 117.40.50
ON 3 WE+ EZ+
250/10
tips grazed+
PIX DI010804 1-23
Nyoman
11:05 01/08

5.1. Examples of grazers

Grazing by herbivorous marine animals has been a problem since the beginning of the development of eucheuma seaplant agronomics (Doty, 1973; Parker, 1974; Doty and Alvarez, 1981) but there have been few published studies.

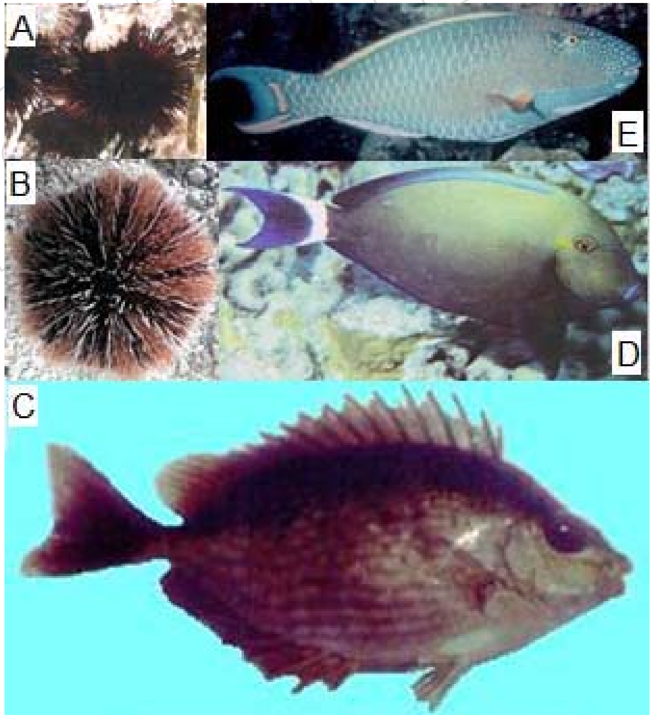
Plate 5-1. Grazer sizes range from the very small (e.g. apple snail, below left) to the fairly large (e.g. green turtle, Chelonia mydas, below right).

The presence of grazers is often due to placement of farm habitats in or near to seagrass beds and other areas where marine herbivores have endemic populations. In some cases herbivores may be introduced through transport of propagules among farm locations. In other cases herbivores come to farms when schools of fish pass through them during certain seasons or life-cycle stages.

Russell (1983) and Uy *et al.* (1998) lent formal confirmation to common observations of farmers when they observed that fish selectively graze smaller branches of eucheuma seaplants. Juvenile parrotfish (scarids) and surgeonfish (acanthurids) have been observed to consume as much as 50-80% of eucheuma seaplant populations at 0.5 and 2.0 m depth (Russell, 1983) and rabbitfish (siganids) are commonly seen to be feeding on eucheuma seaplants. Most fish seem to be "tip nippers". Other herbivorous fish families including puffer fish are known or suspected to be eucheuma grazers and a variety of invertebrates (including holothurians and crustacea) are commonly seen in the vicinity of eucheuma seaplant farms. The author has received numerous reports of star fish and sea cucumbers eating seaplant crops. **Herbivory on eucheuma seaplants has implications for polyculture and is a subject with abundant scope for useful study.**

If farms are not placed in the midst of grazer habitat they are far less likely to cause problems – this is a "no-brainer" to consider.

Plate 5-2. The **s**ea urchin species Diadema setosum (A) and Tripneustes gratilla (B) are common in the vicinity of eucheuma seaplant farms. They appear to be "planers", "gougers" and "strippers". The fish grazers shown include Siganus javus (C), the surgeonfish Acanthurus mata (D) and the parrot fish Cetoscarus bicolor (E).



Farm habitats placed on or near the sea floor for several months or years sometimes acquire localised "population explosions" of grazers.

5.2. Types of grazer damage

Plate 5-3.
Gouging is the sort of damage where small chunks of pigmented tissue are removed as on the thallus shown left. This pattern seems typical of snails and small sea urchins.

Plate 5-6.
Tip-nipping
occurs when growing tips are bitten off. In the plant at right all tips have been nipped but new ones are growing back. Tip-nipping is commonly seen and is often attributed to rabbitfish and juvenile surgeonfish or parrotfish.

Plate 5-4.
Planing is the sort of damage where the side of a branch is flattened by removal of tissue as if by a plane. This pattern seems typical of the larger sea urchins.

Plate 5-7.
Total damage
can occur as in the plant shown right. This plant seems to have incurred all of the types of grazer damage described here except total loss.

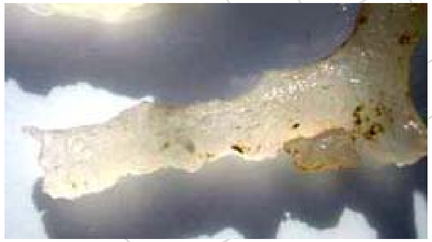


Plate 5-5.
Stripping
occurs when gouging or planing is so severe as to cause complete removal of the plants' pigmented cortical layers as shown left.

Plate 5-8.
Plants just gone as if chomped off in one bite? This can be done by green turtles (Chelonia mydas). Turtles can be kept out of farms by sturdy fences but avoid planting where they feed if you can.

5.3. Control and prevention of grazing

Attempts to "engineer" ways out of grazing problems have generally proven to be expensive and futile.

Grazing can be stopped in a variety of ways but few methods are both environmentally acceptable and economically feasible.

OK **The best "green" ways to deal with grazers are:**

1. AVOID THEM - Place farm habitats in locations where endemic grazer populations are not abundant; for example by placing floating habitats in water several meters deep over muddy or sandy bottom.

2. SWAMP THEM OUT - Build eucheuma seaplant populations to a "critical mass" where any grazing pressure is trivial relative to the total biomass and production; then accept some losses. This is a widest-spread method of dealing with grazers.

3. BLOCK THEM - Use barrier nets or enclosures on a selective basis during seedstock production or to prevent the entrance of large grazers such as turtles.

4. EVADE THEM - Crop back and wait out seasonal grazing periods if they last for only a few weeks (e.g. in Bali, Indonesia).

5. CATCH THEM - Many marine herbivores are good to eat. Some grazers have aquaculture potential (e.g. abalone; rabbitfish).

Plate 5-9. The seaplant farmers at right in Sabah, Malaysia have cottonii drying on the platform beside them as they prepare rabbit fish for lunch.

"Brute force" to combat grazers runs counter to the "go with the flow" approach that has made for economic success in the organic production of eucheuma seaplants.

During more than three decades of dealing with grazer problems in seaplant cultures the author has reached the following conclusions as to why several "red" pest controls fail:

1. POISONS - Pesticides can be effective in ponds, raceways or other enclosures but many toxic chemicals may be needed to combat the wide spectrum of vertebrates and invertebrates found eating seaplants. Also, like fertilizers, they diffuse rapidly in the sea so *in situ* application results in most being wasted and drifting off to contaminate surrounding environments.

2. CHEMICAL DETERRENTS - May work briefly but diffuse and contaminate surrounding environments. Herbivores tend to habituate to the presence of chemicals and other deterrents.

3. AUDITORY, VISUAL, ELECTRICAL AND OTHER DETERRENTS - Fish are not as stupid as most people seem to think. They can habituate and adapt rapidly to a wide variety of deterrents, including "scarecrow-style" devices. Some devices, such as palm fronds, may act as deterrents at first then as attractants later. Like fish, many invertebrate grazers probably also habituate to deterrents. Besides being potentially ineffective, deterrent devices may disrupt populations in surrounding environments.

4. BARRIERS & TRAPS - Can keep herbivores out or pen them in depending on how they are used. Without a doubt the selective use of barriers and traps can have a role in seaplant farming (see "block them" opposite) especially for highly seasonal grazing, for very large grazers or for protecting small plots of high value plants such as a cultivar bank. For the most part they are too expensive to operate as components of crop production systems.

Fortunately there are vast areas where seaplant farming has been successful without resort to drastic grazer control measures.

5.4. Diseases and malnutrition leading to ice-ice

Chronic epiphyte problems have recently caused farm areas to be abandoned in some regions of the Philippines and this problem is in need of thorough investigation. Also, eucheuma seaplant maladies attributed to malnutrition are commonplace as a seasonal event in many areas. Remedial action is usually to "bail out". The malady known as "ice-ice" was identified as a problem early in industry development (Doty and Alvarez, 1975; Uyenco *et al.,* 1981). The term was coined by Filipino farmers to describe the dying tissue devoid of pigment that causes branches to break off . Doty (1978) identified stress as the major factor promoting ice-ice and drew a correlation between its occurrence and that of epiphytes. Progress of the ice-ice syndrome is generally as follows:

Plate 5-10. Stage 1: Clean, vigorously growing plants (below, left) lose pigmentation while remaining healthy in appearance and growth (below, right).

Plate 5-11. Stage 2: In a matter of days loss of pigmentation may become severe (white plants in photo right) and growth rate becomes very low. At this stage if plants are moved to "better water" they may fully recover.

Plate 5-12. Stage 3: New tips, if they occur, tend to be spindly and lacking in vigor (right). In this case the plant has an appearance that is reminiscent of a centipede. There were many tips but the plants were losing weight.

Plate 5-13. Stage 4: Areas devoid of pigmentation appear at intervals on plant thalli (below, left); they weaken and eventually the tissue atrophies, thus causing plant breakage (below, right).

Uyenco *et al.* (1981) noted high populations of bacteria in tissue with ice-ice but concluded that they were secondary problems. Doty (1987) noted that the occurrence of ice-ice was seasonal and was correlated with changes in the monsoon (Doty and Alvarez, 1975). Largo *et al.* (1995) showed that certain bacteria appeared to be capable of inducing ice-ice in stressed propagules and noted that that several abiotic factors could generate symptoms. Light intensity of less than 50 micromol photon m2 s; salinity of less than 20 ppt.; and high temperature (up to 35ºC) induced ice-ice in K alvarezii planted in sub-tropical waters in southern Japan *(op. cit*.).

Eucheuma seaplant metabolites may also play a role in ice-ice formation. Mtolera *et al.* (1996) observed that E. denticulatum produced volatile halocarbons (VHC) in high-light and low-CO_2 environments . Pedersen *et al.* (1996) demonstrated that high VHC levels produced diseases in Gracilaria cornea and a similar phenomenon may occur with eucheuma seaplants, especially in low-water-flow, high-unmixed-boundary-layer conditions.

5.5. Weeds, epiphytes & epizoa

If weeds, epiphytes, epizoa or disease (W.E.E.D.) become prominent the most useful agronomic response is generally to crop out the farm and move it and / or replace propagules with healthy material. Three types of weeds/epiphytes can be recognised:

1. Macroalgae such as Ulva spp., Enteromorpha spp., Cladophora spp. and several other genera that drift or settle; then tangle or attach to farm habitat structures or to the crop. Such infestations are usually acutely seasonal and have a duration of a few weeks or months.

2. True epiphytes such as Neosiphonia; often chronic; usually filamentous algae; attach to cortical layer; damage plants (Ask, 1999; Hurtado *et. al.*, 2005).

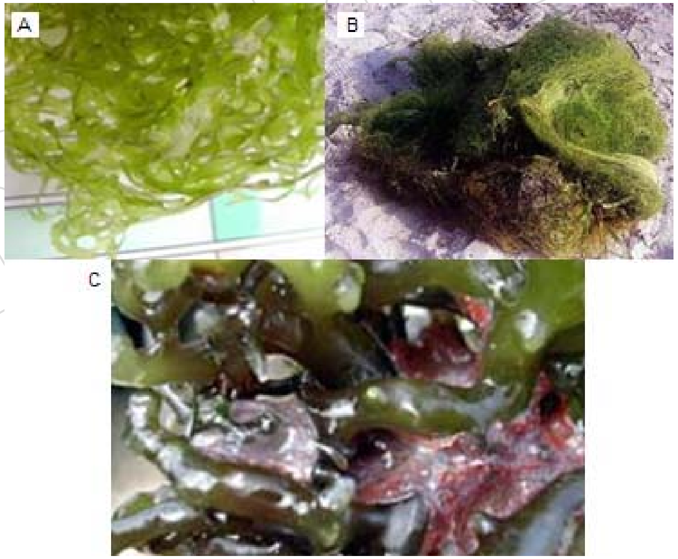
3. Microalgae such as diatoms that form a "scum" on the crop. This problem can be caused by poor water quality (low flow; high silicon; eutrophication).

Seasonal weeds were noted as a serious problem from the beginnings of eucheuma seaplant cultivation (Parker, 1974) but the problem is still not well studied. Fletcher (1995) provided a review of the impacts of pest weeds on Gracilaria cultivation that is also relevant to the situation with eucheuma seaplants.

Hurtado *et al*. (2005) have reported on cases of a persistent "goose bump" epiphyte infestation caused by *Neosiphonia spp.* (originally identified as Polysiphonia spp.). This problem was associated with 'ice-ice' and led to severe reduction in the production of Kappaphycus from farms in the northern Philippines. The degree of infestation was strongly correlated with low water motion or high light conditions. The occurrence of Neosiphonia registered as high as 65% at sheltered sites but was as low as 17% at sites with vigorous water motion. Though this study was preliminary it demonstrated that Neosiphonia infestation can pose a tremendous problem to eucheuma seaplant farmers. Clearly such phenomena are worthy of further investigation.

Settling of loose silt and / or microalgae is common in areas with murky and / or still water. Farmers can combat this by shaking plants (daily if possible) during times of tidal flow.

Plate 5-14. Various Ulva spp. (A) are seasonal weeds. Severe weed infestations (B) may smother crops. Animals such as bryozoans also grow on crops (C); especially on old tissue. Small organisms can form a "scum" on the crop that diminishes growth and devalues the crop.



Current protocols for managing non-epiphytic weeds call for watching seasonal patterns, then immediately removing weeds manually as soon as they appear in order to prevent their reproduction and spreading (e.g. Ask, 1999). Removed pest weeds should be taken to land and used as fodder or compost material.

In the case of epiphytes and epizoa there is little choice but to crop out old stock and replace it with clean propagules. Such material may be saleable if it is not too grossly infested.

5.6. Green light to farm success

Plate 5-15. Plants are healthy, with good color and no more than trace amounts of grazers or weeds, epiphytes, epizoa, or disease (W.E.E.D.).

Plate 5-16. Crops that look like the ones shown below are the rule rather than the exception in many places where eucheuma seaplants have been grown for several years - even decades. One of the secrets to this success is that the carrying capacity of local environments should not be reduced by poor farming practices.

Plate 5-17. The plants shown in plates 5-15, 5-16 and below left were in condition "GN-1". They had excellent color density, no grazing and very clean thalli. The plants shown below right are "GN-2" plants. They appeared to be in good condition but pigmentation was weakening. Such plants must be watched to see whether they are trending toward bleaching (condition yellow).

Some areas appear to enter a period of poor growth after several years of farming. These usually appear to be places that are very heavily planted - usually using "off bottom" methods close to sea floors that have been subjected to considerable direct, secondary, collateral or indirect damage. Such places may recover after a few fallow years but should be replanted using less environmentally stressful agronomic practices.

6.1. Types of farm habitat system

The most obvious part of seaplant farms is the habitat structures that support plants growing in the sea. These structures absorb most of the farm's capital and operating costs. The list on page 6-2 outlines the elements of habitat systems. The five features that characterize farm habitat systems are:

1. Type of substrate or enclosure that holds crops within farm boundaries.
2. Position or location of the substrate or enclosure relative to the sea floor and the sea surface.
4. Method by which the substrate or enclosure is fixed, suspended or held in place within the farm area.
5. Method by which propagules are attached to the substrate or suspended within the enclosure.
3. Whether the substrate or enclosure orientation is horizontal; is perpendicular to the sea surface or has no fixed orientation.

The choice of habitat system position and orientation is governed by many local factors including the availability of space, water motion, water depth, ease of handling and cost of materials. Generally horizontal systems with tightly stretched lines are preferred because they minimize line-tangling and are easiest to handle during planting and harvesting. Some locations conditions permit a perpendicular orientation.

Figure 6-1. Seaplant habitat-system positions and orientations.

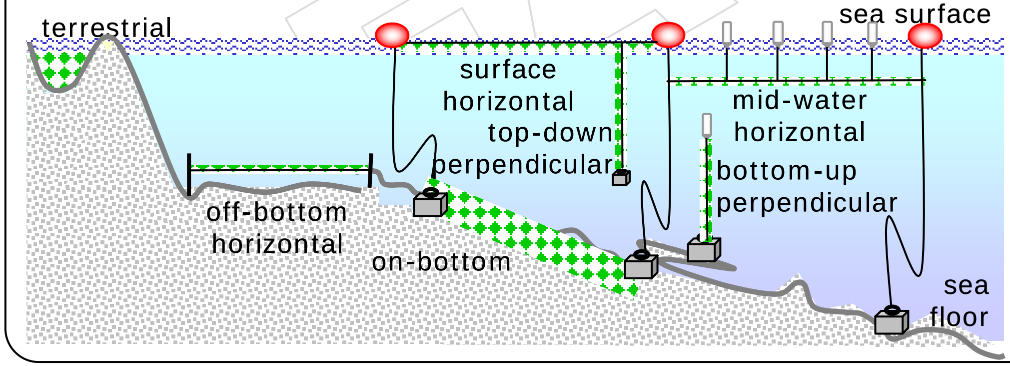


Table 6-1. Elements of farm habitat systems.

Substrate or enclosure type
Coral or stones - Propagules attached directly to stones or coral fragments using string, elastic bands or netting.
Pens, cages or sacks – Commonly used for temporary holding pf propagules
Line - Fishing line or twine; usually 3-8 mm diameter
Net bags or tubes - Nets bags or tubes made from netting
Film bags or tubes - Plastic bags or tubes with or without perforations
Ponds/raceways - Ponds or raceways built on land; water fed by tide or pumps

Position or location
On-bottom - Propagules placed on sea floor
Off bottom - Propagules placed just above sea floor
Mid water - Propagules placed in water column
Surface - Propagules floating at or near sea surface
On land - Systems placed in ponds on land; intertidal or above tides

Orientation
Horizontal - Substrate horizontal to sea floor/surface
Perpendicular - Substrate vertical / perpendicular to sea floor/surface
Mixed - Propagules unattached; mixed by physical agitation

Fixation method
Stakes or rocks - Support substrate or enclosures on or near sea floor
Floats and anchors - Support substrate or enclosures in water column or at/near sea surface
Rafts - Substrate or enclosures suspended from bamboo or plastic-tube rafts
Terrestrial – Pond systems on land; intertidal or above tides

Attachment method
None – Loose propagules sitting on sea floor or mixed by agitation
Enclosure - Propagules unattached and contained in enclosure
Tie - Propagules individually tied to substrate using knots
Loop - Propagules individually attached to substrate using loops

6.2. Natural and "on-bottom" habitats

Eucheuma seaplants were harvested from wild stocks in China, Indonesia, the Philippines, Malaysia, Tanzania and Indonesia commencing in the mid 20th century. Total quantities never exceeded about 1,000 tons per annum and the harvests were generally of mixed species. Early cultivation efforts involved broadcasting of cuttings over the sea floor; attachment to stones or coral fragments using string or elastic bands; or sandwiching cuttings to the sea floor using nets to make a "lawn".

Plate 6-1. Wild Kappaphycus with the flattened appearance of the K. cottonii type. Growing in typical habitat among corals, sea grasses and other seaplants (Sabah, Malaysia, 1977).

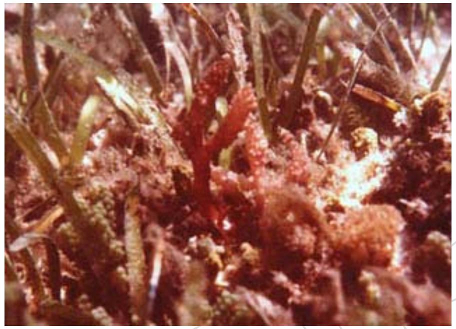


Plate 6-2. Wild Kappaphycus with the flattened appearance of the K. cottonii type growing in typical habitat among corals, sea grasses and other seaplants (Sabah, Malaysia, 1977).

"On-bottom" methods caused localised eucheuma seaplant population increases but were laborious, disrupted the benthos and allowed for little crop control.

Plate 6-3. Wild Kappaphycus. Is still harvested in some regions of Indonesia (Sulawesi Tenggara, 2005).

Plate 6-4. Betaphycus gelatinum cultivated on stones and coral, China 1988.

Plate 6-5. Grazing by sea urchins and other herbivores was a major problem "on-bottom".

6.3. "Off-bottom" habitat systems

State-of-the-art during the early 1970s was large-mesh nylon monoline nets with propagules tied at junctions about 40 cm apart.

Plate 6-6. Right: K. alvarezii growing on nets in a test plot in Sabah (1977). The "Tambalang" cultivar originated near this site.

Nets were generally supported just above the sea floor by tethers that secured them to coral heads, rocks or mangrove-wood stakes driven into the sea floor; generally over the types seagrass beds that serve as natural eucheuma seaplant habitat. The system of using large-mesh nets fell into disuse when it was found that plants could be spaced as little as 15-20 cm. apart. Nets of this mesh are laborious to make, impede walking through farms and offer no advantage over monolines. Since the mid-1970s "Off-bottom" monoline systems and floating systems have been the preferred habitat structures at most farm locations.

Plate 6-7. The sort of scene shown below is a local low-tide feature of beaches in eucheuma seaplant farm areas. (Tanzania, 1991)

Mangrove wood is commonly used as stake material but cutting is banned in many places.

Plate 6-8. These off-bottom farms on Nusa Penida, Bali have produced eucheuma seaplants continuously since 1987.

Plate 6-9. Right: Lines may be suspended above the sea floor using stones (right; India; 2003).

Plate 6-10. Left: A more frequently used method is to suspend lines using stakes made from concrete, steel or rot resistant wood (left; Tanzania; 1991).

Plate 6-11. Right: Stakes are normally driven into a soft limestone seafloor; often with pre-drilled holes (Right; Bali; ca. 1989).

6.4. “Long stake” habitat systems

The “long-stake” method is commonly employed on shallow-water farm sites that are located in areas with a soft mud and/or sand bottom. Lines of attached propagules are strung like clotheslines between the stakes.

Plate 6-12. The “long stake” system is commonly used in Sulawesi Tenggara (below, 2005). Usually long-stake farms are placed in shallow waters that are reachable by small boats or canoes even during low tides.

Plate 6-13. Lines of various lengths can be suspended using the long-stake system. The longest can exceed 200 meters. Generally small floats are placed every few meters along the lines and in many cases the lines are totally submerged during high tides so from a distance the only sign of seaweed farms being present is the stakes protruding above the sea surface. It is common practice for farmers to mark the perimeters of their farms with flags or signs as seen in Plate 6-14.(Sulawesi Tenggara, 2005)

Plate 6-14. When using the long-stake method farmers must be careful about the level at which they attach lines. If they are too far up the stake plants at line ends may receive excessive exposure to air where they can desiccate and die. (Sulawesi Tenggara, 2005)

Plate 6-15. The long-stake method is often used in close proximity to mangrove (manggal) areas. (Sulawesi Tenggara, 2005)

6.5. “Floating line” habitat systems

Floating short-line or long-line systems have found favor especially where eucheuma seaplants are grown in deep water. If proper procedures are followed this can be an environment-friendly farming method.

Plate 6-16. Farms can be placed in deep water (e.g. 3+ metres) and they can be planted over muddy or sandy bottom where plant fragments do not attach (Pulau Nain; North Sulawesi, Indonesia; 2004).

Plate 6-17. The use of boats minimizes sea floor damage (Bantaeng, South Sulawesi, Indonesia, 2004).

Plate 6-18. The "long-lines" illustrated here work well in deep water areas. Lines are widely spaced to prevent tangling. Where space is limited lines can be placed close together and tangling can be minimized through the use of wood or bamboo spacers. (Sabah, Malaysia, 2002).

Figure 6-2. Example of a type longline system commonly used in Indonesia and Malaysia.

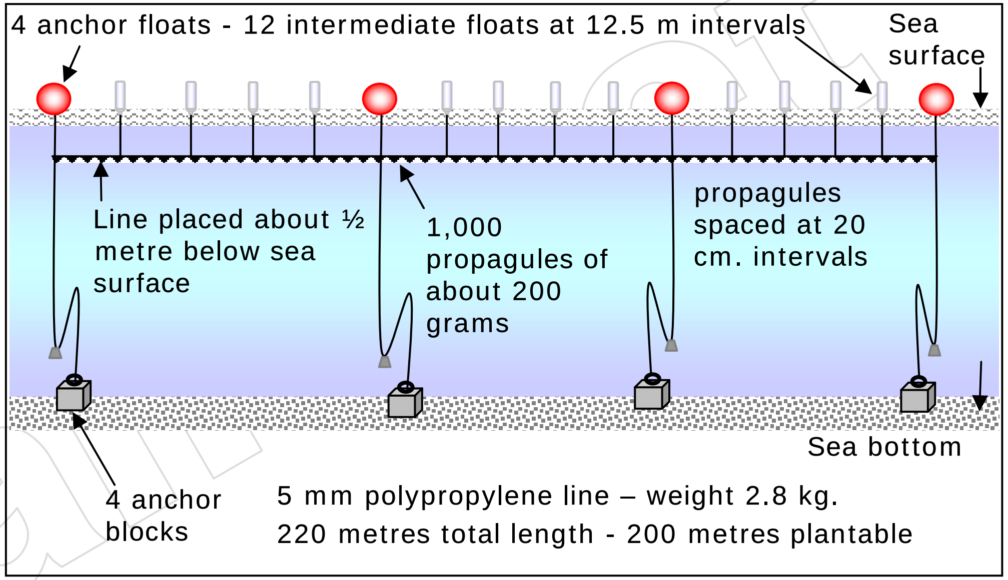


Plate 6-19. Spacers permit lines to be fastened closely together if need be (Sulawesi Tenggara, 2005).

6.6. “Raft” habitat systems

Raft systems have found favor where eucheuma seaplants are grown in areas with plentiful, large bamboo and/or sea floors that are inappropriate and/or too deep for on/off-bottom systems. As in the case of the long-stake and floating-line systems the raft method can also be environment-friendly. Raft farms can be placed in any depth of water; farms can be planted over bottom where plant fragments do not attach; and boats can be used to minimize sea floor damage.

Plate 6-20. Mr. Made Simbik inspects a farm in Bali, Indonesia and offers advice. This type of technical assistance catalyses farm development.

Plate 6-21. Top right: 10 x 10 m. rafts commonly seen in Madura, Indonesia.
Plate 6-22. Lower right: Madura seaplant farms support at least 1,000 farm families.
Plate 6-23. Below: Kabupaten Sumenep, Madura has 30 km coastline that is virtually continuous eucheuma seaplant farm.

Plate 6-24. One advantage of raft systems is that units can be brought to shore-side work areas so work on the water is minimized. This saves on costs and reduces safety hazards.

Plate 6-25 Right: The 2.5 x 5 m. rafts shown here are typical of Gunung Payong in Bali. Bamboo is normally used but plastic piping can also be utilised.
Plate 6-26. Below: This site has supported seaplant farms for about 20 years but they are now being displaced by resort hotel activities.

6.7. Pond and raceway systems

Terrestrial pond and raceway systems permit a high degree of control over culture conditions but control is achieved at high capital- and operating-cost. Propagules may be unattached and agitated; may be attached to substrate within tanks or raceways; or may be placed within sub-enclosures such as nets and tubes. As in the case of net and tube systems some variants of pond or raceway systems may prove to be cost effective for cultivation of eucheuma seaplants as technology and agronomy protocols advance or as commercial conditions change.

Agitation involves substantial energy consumption. That tends to restrict these systems to high-value crops. Tank and raceway systems are useful for experimental work, however, and can also be used in seedstock selection programs. From time to time attempts have been made to integrate eucheuma seaplants into land-based polyculture systems that include fish, crustacea and molluscs but this approach has not yet been widely adopted.

Plate 6-27. Left: One common means for maintaining unattached propagules in suspension is air bubbles from a blower.

Plate 6-28. Right: Another common means for maintaining propagules in suspension is paddle wheels such as this one in Canada.

Since the beginnings of eucheuma seaplant cultivation a bewildering variety of propagule suspension systems has been tried. Some systems have involved placement of loose or tied plants within pens, sacks, cages, bags or tubes made from netting or perforated plastic. Bag and tube systems have been tried with several species of seaplant. Their use is sometimes motivated by attempts to reduce the labor of attaching or confining plants; especially with small species. Other motives include protection from grazers and prevention of plant losses through breakage.

Plate 6-29. *Chondrus crispus* growing in a bag in quarantine. Mexico; 1996.

Although "enclosure" methods are commonly used for temporary holding of live propagules they have never gained popularity for crop grow-out because their efficacy seldom offsets the lower costs typical of "attach-to-string" methods.

Plate 6-30. Below: Sacks or pens can be used to hold plants after harvesting or before planting (left; India; 2002). Sometimes plants are grown inside cages (right; Bicol, Philippines; 1991).

The jury is still out on enclosure cultivation of eucheuma seaplants. Variants of such systems may prove to be cost-effective as technology and agronomy protocols advance.

6.8. Attaching and detaching propagules

Attaching individual propagules ("cuttings" or "seedlings") to pieces of string (lines) is the most laborious aspect of eucheuma seaplant farming.

Plate 6-31. Right: A line ready for propagules. Note that the "tie-ties" are already attached to the main line at intervals of about 20 cm.

Plate 6-32. Typically 3-4 hours/day per person are spent tying propagules to lines. Loops or tie-ties can generally be recycled for several crops (Right: Tamil Nadu, India; 2002).

Plate 6-33. Harvesting is much less laborious than attaching plants. In the photo right a line is being "stripped" by being drawn through a hole in a piece of wood. This cuts plants from the line without removing tie-ties or loops. This practice minimizes mixing of string or raffia with the crop.

Several types of substrate can be used for the suspension of eucheuma seaplants in the water column.

Plate 6-34. Nylon monoline was once widely used. It is durable but is expensive and difficult to handle. It is seldom seen on eucheuma seaplant farms nowadays except as a binding material for rafts.

Plate 6-35. Braided rope or string is by far the predominant type of substrate that is used for attachment of eucheuma seaplants on farms today. Polypropylene line of about 4-6 mm diameter is the most commonly used but hemp or sisal rope is sometimes employed.

Plate 6-36. Woven strapping is used as a suspension material for eucheuma seaplants in some regions where it is cheap and available. This is a very durable material but it is somewhat awkward to handle.

Plate 6-37. Raffia is commonly used for loops or ties. It is not durable or strong enough for routine use as main lines but is sometimes utilized for this application if better materials are less available.

Click to table of contents

6.9. Attaching and detaching propagules

Within the past few years "loop" methods have developed in several regions of Indonesia. These methods have several advantages relative to the practice of tying propagules using knots. Labor involved in attaching propagules is much reduced and planting lines with loops can typically be recycled several times. Furthermore the crop has greater value because it is not adulterated with raffia and string fragments that create processing difficulties.

Plate 6-38. Besides being work the process of attaching plants is a social activity. Once the skill is learned experienced “loopers” can plant lines very rapidly and the use of loops speeds up recycling of lines since knots do not need to be untied and retied.

Plate 6-39. Right: The lasso loop. This is not commonly found but it seems to work as well as the long loop and the short loop illustrated in Plates 6-40 and 6-41.

Plate 6-40. Left: The short loop; also called he “Made loop” after Mr. Made Simbik of Bali.

Plate 6-41. The long loop (below) is commonly used in Sulawesi and Flores in Indonesia.

One important thing to remember about attachment materials is that no buyer wants to find them in the crop. They are contaminants that must be removed.

6.10. Seasonal variations in growth

Variation in growth has been observed for eucheuma seaplants both within and between annual periods. Productivity variations that appear as regular annual cycles are commonly referred to as "seasonality". Growth differences between years tend to be associated with macro-climatic phenomena such as el Niño or la Niña. Generalised variations in farm productivity were observed early in the development of eucheuma seaplant farming) but these phenomena are still poorly understood.

Table 6-2. 1976-77 Mean Specific Growth Rates (after Doty, 1987)

	K. alvarezii	***K. striatum***	***E. denticulatum***
Spring	5.25	3.95	3.51
Summer	6.23	3.33	4.05
Fall	4.41	2.98	3.52
Winter	4.15	2.98	3.35

Some seasonality appears in most commercial eucheuma seaplant farming areas. Direct effects on the crop seem to be related to meteorological and oceanographic phenomena such as wind direction, water movement, nutrient availability and temperature. Secondary phenomena include seasonal grazing activity and seasonal pest, weed or disease problems.

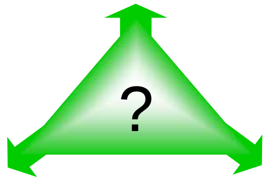
Plate 6-42. One common phenomenon is loss of color that is related to the seasonal availability of nitrogen and other nutrients. The plants shown below were from the same clone and were grown at the same location but were photographed during a peak growth season (left) and a slower growth season (right) (Tamil Nadu, India, 2001-2002)..

In most tropical regions of the Indian and Pacific Oceans there are seasonal shifts in prevailing wind direction and general weather conditions correlated with "monsoons". In some farm areas the monsoons cause acceptable variations in farm productivity but in others there may be changes that make the farming of certain sites uneconomic during some seasons.

When farm areas exhibit strong seasonality effects there is little that can be done other than to relocate the farm. When and how to do this is determined by the effective use of environmental monitoring and crop-logging programs (whether intuitive or formalized) and the development of effective controls or remedial actions. Farmers basically have three choices if farming becomes seasonally uneconomic at particular sites (see Figure 6-3). The farmer's decision generally depends on current market conditions and on the availability of suitable alternate planting sites.

Figure 6-3. Transfer, move or harvest and sell; these are the three choices if strong seasonality phenomena impair farm productivity.

Transfer propagules to a location that permits plant survival and wait for a favorable seasonal change?



Harvest and sell? **Move the farm** ?

Long-term farm productivity variation seems to be poorly understood. Attribution of effects to el Niño or la Niña attach a name to phenomena but contribute little by way of explanation... especially where there is weak correlation to begin with. For example during 1998-1999 poorer-than-previously cottonii growth was reported to the author by various informants in sites as widespread as the Sulu Sea and Zanzibar, yet the productivity of spinosum (E. denticulatum) continued undiminished. In some areas the commercial cultivation of cottonii ceased and spinosum replaced it where market conditions permitted.

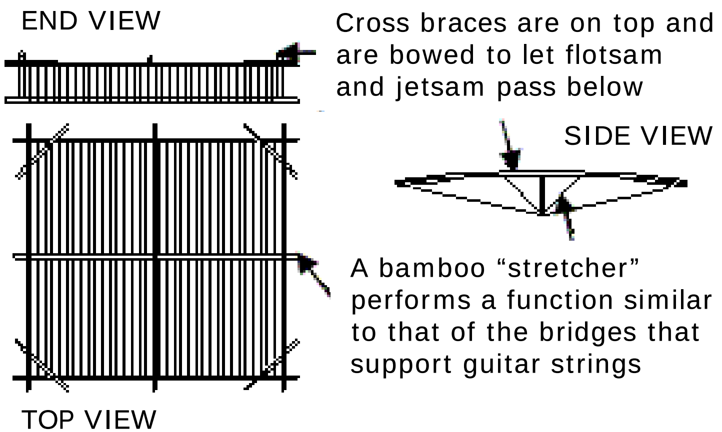
6.11. Severe weather events

Typhoons and seasonally harsh weather prevent sustained economically viable seaplant farming in some tropical areas or restrict farming to certain seasons.

Plate 6-43. This location in India is calm enough for seaplant farming during the NW monsoon but has wave action such as this during the SW monsoon. (Tamil Nadu ca. 2002)

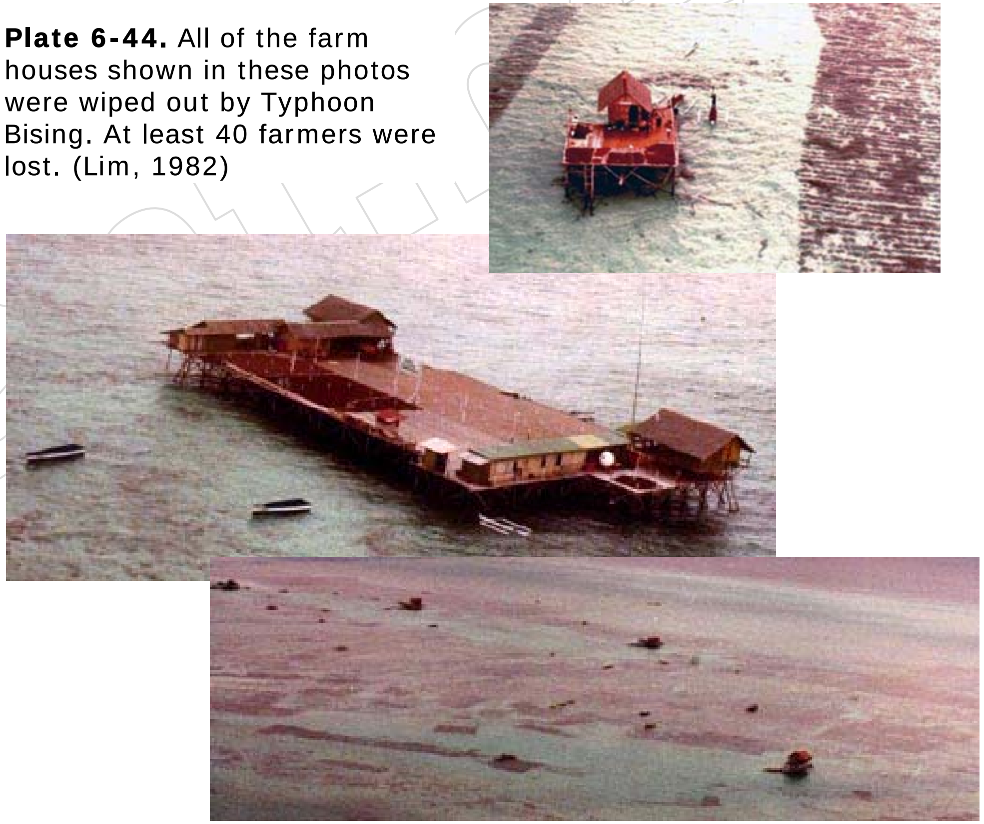
Drifting logs and misdirected boats can damage farms and all manner of flotsam and jetsam can foul floating gear. Farmers cannot anticipate events such as these and there is little that they can do to prevent such random damage. On destruction by unpredictable events the most economic response is usually to repair broken gear, gather and reattach broken thalli and harvest those not good for replanting.

Figure 6-4. Gear damage can be minimized or prevented by proper design and construction. For example the type of raft shown above minimizes tangling of flotsam and jetsam in the lines.



On the day after Typhoon Bising in the Bohol region of the Philippines more than 100 eucheuma seaplant farms and farmhouses had totally disappeared including the ones shown below. In this and other cases farmers were actively repairing and replanting their farms the day after such devastating events.

Plate 6-44. All of the farm houses shown in these photos were wiped out by Typhoon Bising. At least 40 farmers were lost. (Lim, 1982)



Seaplant farmers must treat the forces of nature with respect. Many people lost their lives during typhoon Bising because typhoon warnings were unheeded due to previous "false alarms".

Click to table of contents

6.12. Farm placement options

The basic elements of seaplant growth dictate that successful farm systems must have the key features listed below:

1. Large surface area exposed to sunlight that has optimum characteristics (photoperiod, intensity, wavelength).
2. Effective, even water flow to and from all plants in the system.
3. Even dispersion of plants throughout farm sites.
4. Amenable to frequent cropping, cleaning and tending so weeds, pests, disease and fouling organisms cannot overrun seaplant cultures.
5. Rugged enough to withstand the substantial hydraulic forces of moving water.
6. Environmental conditions as close to ideal as possible for the crops being grown.
7. Minimal fixed and variable production costs.
8. Protected from weather and sea conditions beyond farm habitats' structural limits.
9. Secure from human interference such as pilferage, vandalism and accidental damage from boats.

These features have implications for the types of culture systems that can be used for seaplant cultivation. For example:

1. Enclosures or suspension systems must expose the plants to both light and water flow so large volume-to-surface enclosures similar to most fish cages cannot be used.
2. Plants must be separated and suspended by the use of physical structures (e.g. cages or ties on ropes) and/or applied force (e.g. air and paddle-wheel agitation).
3. Plants and animals can be combined in properly designed integrated systems to their mutual benefit.

An effective way to find the best farm sites is to plant test plots and expand where plants grow best.

Only growing crops over several seasons confirms which locales are best. Site selection is a critical decision that leads either to project failure or to success and competitive advantage. The critical factors necessary at a good site are:

1. Communities of people willing and able to become seaplant farmers.
2. Clean, nutrient-rich water at the right temperature.
3. Low probability of *force majeur* episodes due to natural or human causes.
4. Access to essential inputs, infrastructure and resources at attractive prices.
5. Stable, friendly climate for business, political and socio-economic activities.

Plate 6-45. This region in Bali has supported seaplant farming continuously since 1985. Barrier reefs protect farms but allow nutrient-rich water to enter and metabolite laden water to be flushed away.

6.13. Farm placement options

Farms can be placed in a variety of exposures ranging from land-based or inter-tidal ponds through protected waters to open sea.

Figure 6-5. Four farm placement options are illustrated below.

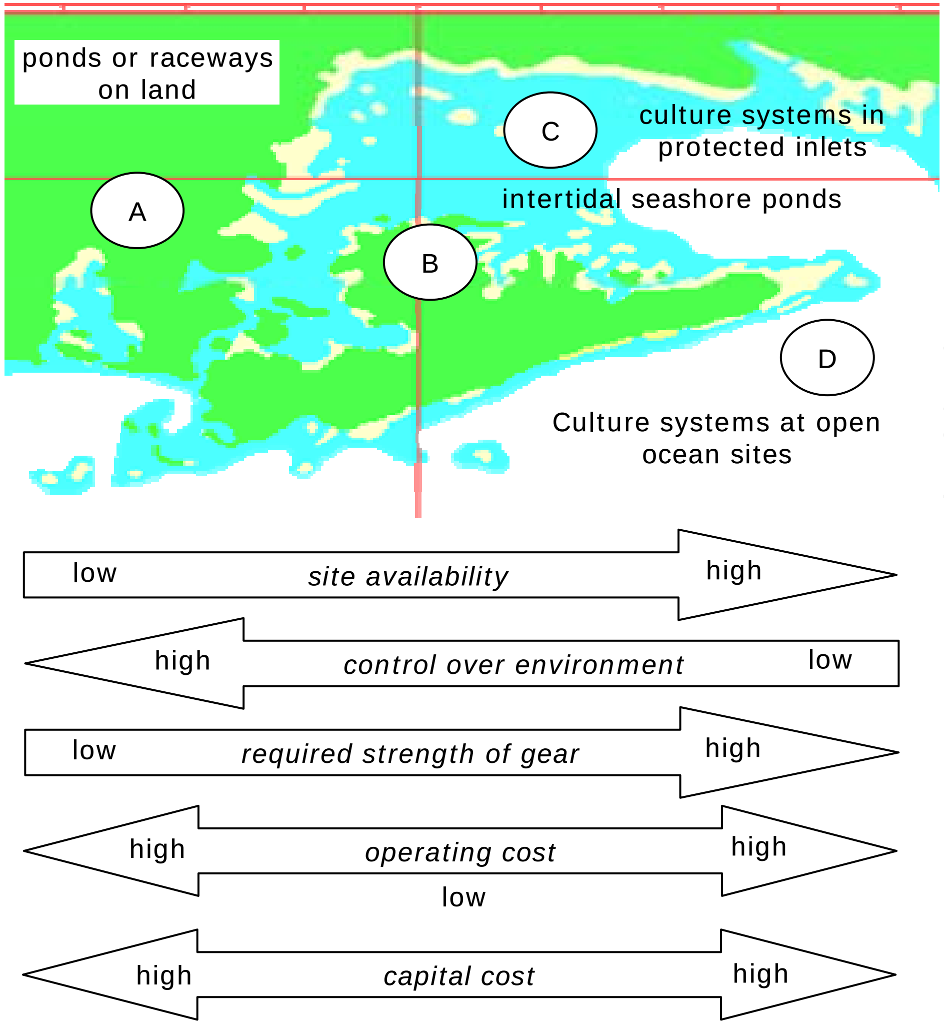


Table 6-3. Choice of placement strategy depends on a balance of costs and benefits or is dictated by the geography and foreshore usage patterns of a given region. Farm system types can be compared and contrasted as shown below.

Type A systems

Type A systems are semi-enclosed or enclosed land-bound systems. They are expensive to build and operate. Such systems tend to be complex and "high-tech" in nature and the offer the potential for exercising a high degree of control over culture conditions. They are best suited to high-unit-value crops.

Type B systems

Type B systems are tidal ponds such as those used for prawns, milkfish and Gracilaria. They are not used extensively for eucheuma seaplants because they tend toward water quality and environmental fluctuations. Sometimes these systems can embody the worst characteristics of Type A and Type C systems.

Type C systems

Most carrageenophytes are raised in Type C systems. Structures are placed in protected salt water bodies such as bays, channels and other inlets. Type C systems are also used for Porphyra, Laminaria and other seaplants. They work well if they are placed where seasonal climatic shifts do not cause low growth, pest problems or crop mortality. The best Type C sites are often near wave and current action.. One problem is that suitable sites tend to be scarce and have high value for other uses such as recreation, tourism, port facilities or other aquaculture uses.

Type D systems

Type D systems are open-water ocean systems. They are essentially rugged and robust versions of Type C systems that can thrive in the exposed areas where weak or poorly designed gear cannot survive. An advantage of Type D systems is that there are large available areas where they can be installed and sites tend to be less effected by seasonality, grazing and some other problems of near shore operations.

6.14. Site selection tools and information

By using the proper tools, data products and procedures one can select minimal-risk sites for farm development. It must always be kept in mind, however, that the installation and monitoring of test plots is essential before site potential can be established with certainty.

The survey team must collect as much information as possible including tide tables or tide prediction programs; nautical charts of the area; historical weather records; and any oceanographic information that may be available. Information about local marine flora and fauna are invaluable in those rare instances where they are available.

Plate 6-46. Basic survey tools include a good boat, a waterproof case (e.g. Pelican Case illustrated), a rugged notebook computer, a mask and fins, binoculars, a GPS and a waterproof digital camera.

Figure 6-6. A good set of nautical charts and tide tables that cover the survey area will save much time and effort during searches for suitable farm sites.

Plate 6-47. Surveys must include "ground truthing. It is necessary to get in the water to see what is really there.

Plate 6-48. Nothing beats aerial surveys for overviews and monitoring of farm sites. Most light, microlight or ultralight aircraft can be used for this function. The photos below right show aerial views of cottonii farms in Bohol, Philippines (ca. 1988).

7.1. Crop growth and yields

Attach-to-line methods predominate among commercial eucheuma seaplants farms so yields are usefully calculated as biomass produced per length of line. Traditionally farm productivity is referred to in terms of production per unit of area. For comparative purposes both measures must be used. In some regions the cost of suspending lines is the most significant parameter of capital cost. In other regions area-access may play a great or a predominant role. There are several reports of eucheuma seaplant productivity in the literature. Generally daily specific growth rates of 2-5% are cited for commercial farms.

Eucheuma seaplant propagules grow at an exponential rate according to the formula (using MS Excel notation):
Final weight = initial weight * (EXP ((SGR/100) * days))

Average line-spacing intervals of 15-20 cm and as much as 200 cm (or more) may be observed on commercial farms depending on the type of method used. Raft methods commonly plant at a density of 50 km. line/ha. of planted area but longlines may have only 5 km./ha.

Figure 7-1. Left: The relationship of line spacing (cm.) to line length (km. per hectare. Right: The relationship of specific growth rate (SGR; in % per day) to crop yield (dry tons per km. line length per annum) for three different starting propagule sizes.

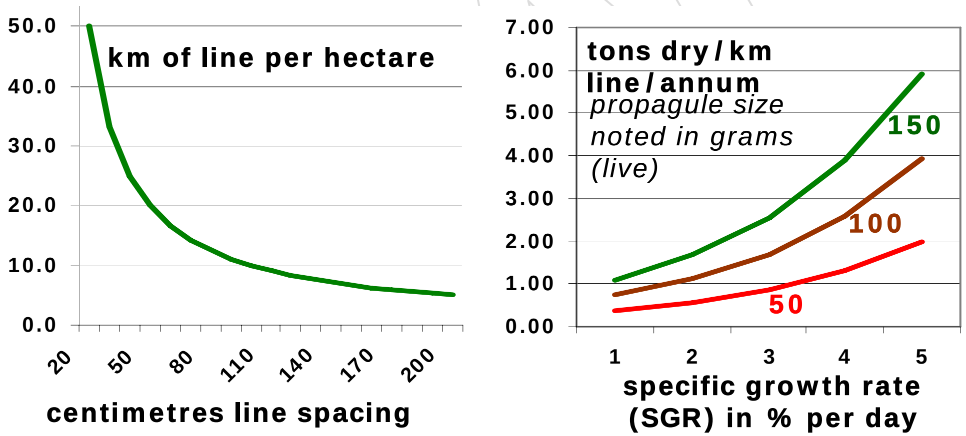
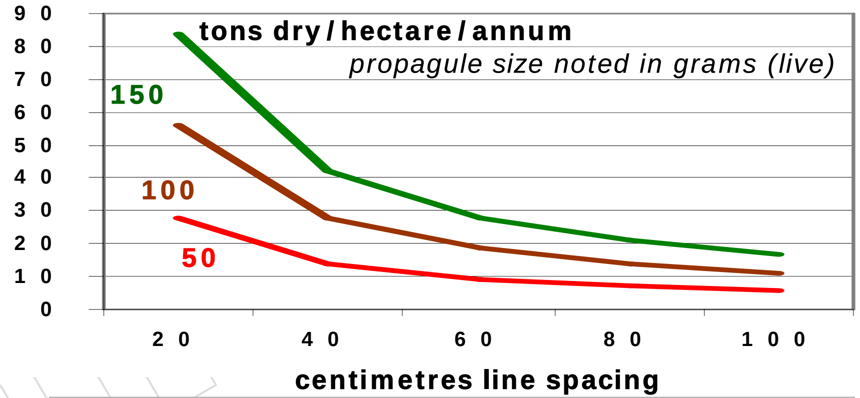


Figure 7-2 and Table 7-1. The graph and table below show annual production rates in mt/ha of planted area assuming 2% SGR and six week cropping cycle for propagule sizes of 50, 100 & 150 gm and line spacing of 20-100 cm.



Propagule Weight (gm.)	50	100	150
Line Spacing (cm)	Tons/ha/yr		
20	28	56	84
40	14	28	42
60	9	19	28
80	7	14	21
100	6	11	17

Note that "SGR" (specific growth rate) is the "net" growth after losses to grazers, breakage and other causes. Yield-per-hectare is for planted area only (does not include channels between plots and other open space in the farm site).

7.2. Crop growth and yields

One of the most common questions from people curious about seaplant farming is "how much do you get per hectare?" The table opposite gives estimates for various combinations of propagule size, line spacing and specific growth rate (SGR). This table assumes that propagules are spaced at 20 cm. intervals along the lines and that the wet : dry ratio is 8:1. It also deducts weight to account for propagules recycled for planting.

Extremely high yields can be achieved under special conditions where large propagules can be planted densely under conditions of high water flow, high nutrient concentration and low enough turbulence to minimize plant breakage. Production of about 12-18 dry tons/ha/yr is fairly typical for well tended family farms but yields several times this level have been observed by the author on well tended plots in the Philippines, Malaysia, India and Indonesia.

Plate 7-1. During intensive cultivation trials Kappaphycus production levels exceeding 50 mt/ha/annum have been observed (e.g. Bali, below).

Exponential growth makes the regeneration of new seedstock from relatively small "gene banks" feasible. In only 18 months as much as 10,000 tons of planting material can be developed from a single 100 gram propagule growing at an average SGR of only 3%/day if propagules are constantly replanted. Exponential growth of eucheuma seaplants can lead to rapid farm development and virtually "explosive" expansion has been demonstrated in several regions once critical masses of farmers and seed-stocks have been established.

Propagules...			Lines...		Dry mt/km of line/mo				
size in grams	mt/km of line	mt per hectare	space cm	km per hectare	SGR 1.0	SGR 2.0	SGR 3.0	SGR 4.0	SGR 5.0
50	0.250	12.5	20	50.0	0.01	0.03	0.05	0.07	0.11
50	0.250	6.3	40	25.0	0.01	0.03	0.05	0.07	0.11
50	0.250	3.1	80	12.5	0.01	0.03	0.05	0.07	0.11
50	0.250	2.5	100	10.0	0.01	0.03	0.05	0.07	0.11
100	0.500	25.0	20	50.0	0.02	0.05	0.09	0.15	0.22
100	0.500	12.5	40	25.0	0.02	0.05	0.09	0.15	0.22
100	0.500	6.3	80	12.5	0.02	0.05	0.09	0.15	0.22
100	0.500	5.0	100	10.0	0.02	0.05	0.09	0.15	0.22
150	0.750	37.5	20	50.0	0.03	0.08	0.14	0.22	0.33
150	0.750	18.8	40	25.0	0.03	0.08	0.14	0.22	0.33
150	0.750	9.4	80	12.5	0.03	0.08	0.14	0.22	0.33
150	0.750	7.5	100	10.0	0.03	0.08	0.14	0.22	0.33
200	1.000	50.0	20	50.0	0.04	0.10	0.18	0.29	0.44
200	1.000	25.0	40	25.0	0.04	0.10	0.18	0.29	0.44
200	1.000	12.5	80	12.5	0.04	0.10	0.18	0.29	0.44
200	1.000	10.0	100	10.0	0.04	0.10	0.18	0.29	0.44

Propagules...			Lines...		Dry mt/ha planted/month				
size in grams	mt/km of line	mt per hectare	space cm	km per hectare	SGR 1.0	SGR 2.0	SGR 3.0	SGR 4.0	SGR 5.0
50	0.250	0.0	20	0.0	0.55	1.28	2.28	3.63	5.44
50	0.250	0.0	40	0.0	0.27	0.64	1.14	1.81	2.72
50	0.250	0.0	80	0.0	0.14	0.32	0.57	0.91	1.36
50	0.250	0.0	100	0.0	0.11	0.26	0.46	0.73	1.09
100	0.500	0.0	20	0.0	1.09	2.57	4.56	7.25	10.88
100	0.500	0.0	40	0.0	0.55	1.28	2.28	3.63	5.44
100	0.500	0.0	80	0.0	0.27	0.64	1.14	1.81	2.72
100	0.500	0.0	100	0.0	0.22	0.51	0.91	1.45	2.18
150	0.750	0.0	20	0.0	1.64	3.85	6.84	10.88	16.32
150	0.750	0.0	40	0.0	0.82	1.93	3.42	5.44	8.16
150	0.750	0.0	80	0.0	0.41	0.96	1.71	2.72	4.08
150	0.750	0.0	100	0.0	0.33	0.77	1.37	2.18	3.26
200	1.000	0.0	20	0.0	2.19	5.14	9.12	14.50	21.76
200	1.000	0.0	40	0.0	1.09	2.57	4.56	7.25	10.88
200	1.000	0.0	80	0.0	0.55	1.28	2.28	3.63	5.44
200	1.000	0.0	100	0.0	0.44	1.03	1.82	2.90	4.35

7.3. Capital cost items for eucheuma seaplant farms

Seven categories of capital item are required for eucheuma seaplant production. Most eucheuma seaplant farms are "shoestring" operations that employ an absolute minimum of capital. They borrow or rent the more expensive items required for seaplant production.

1. Substrate

Nylon monoline was once widely used. It is durable but is expensive and difficult to handle. Braided rope or string is by far the predominant type of substrate that is used for attachment of eucheuma seaplants on farms today. Woven strapping is used is some regions where it is cheap and available. Raffia may be used as both lines and ties. Plants are generally tied using raffia or small string. Nets or bags have been used on a limited scale.

2. Suspension materials

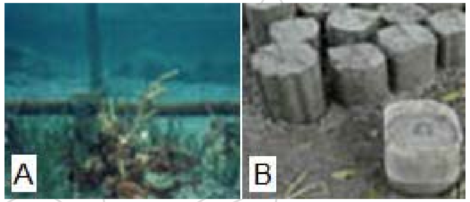
Floats can be made from anything cheap and buoyant including plastic beverage bottles, inflated plastic bags, coconuts, Styrofoam or bamboo. Bamboo, wood and ropes can be used as spreaders that separate lines and keep them from tangling.

Plate 7-2. Thousands of plastic-bottle floats on the water at Manicahan, Zamboanga, Philippines (2004).

Care must be taken to avoid littering of local shorelines and waterways with break-away planting materials such as plastic bottles and rope. When this happens, seaplant farming gets a bad name.

3. Anchoring systems

Plate 7-3. Crop habitat systems are generally anchored in place by stakes driven into the substratum (A) or by anchors made from stones, metal or concrete (B).



4. Real estate

In most S.E. Asian regions farm sites tend to be made available to local farmers by local authorities on an *ad hoc* basis. In other regions (e.g. India) farm concession areas are leased to users by government agencies. Most near-shore areas are public property and are not available for outright ownership.

5. Shelter & post-harvest treatment (PHT) structures

Plate 7-4. Many farmers work in simple shelters that are built over the sea (e.g. right; Bohol, Philippines) or are shore-based near farm sites. These generally have nearby areas and structures for drying the crop. In some cases there may be facilities for washing or chemically treating the crop or for sorting and packaging the crop.

6. Vessels & vehicles

Plate 7-5. Most eucheuma seaplant farms utilise small paddle or wind-driven canoes or larger powered boats for tending crops and for transporting them to market. Some use lorries (trucks) or tractors as well.

Click to table of contents

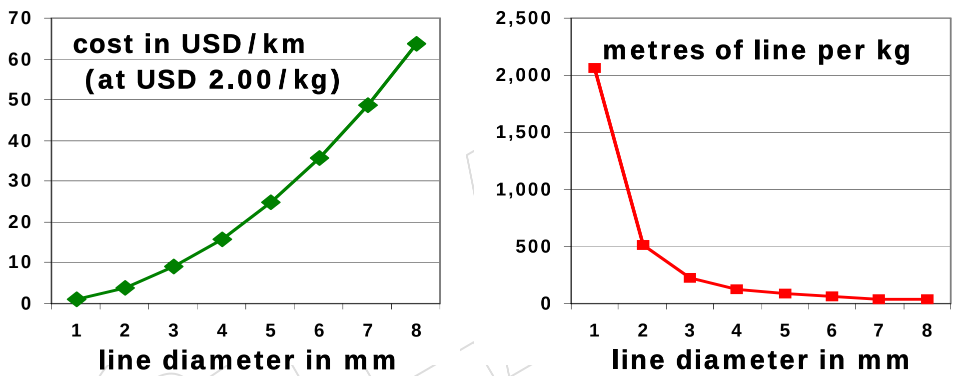
7.4. Capital costs for eucheuma seaplant farms

Seven categories of capital cost apply to eucheuma seaplant production.

1. Substrate

Substrate is usually a major capital item for family farms. Polypropylene (PP) line is the predominant material used. It is generally sold by weight and the cost per unit of length is exponentially related to line diameter so farmers tend to use the smallest line that they can (usually 4-6 mm). PP line degrades under direct sunlight so it must be submerged or protected. It will last 1-3 years depending on care of use. Alternatives to PP line such as woven strapping and nylon monoline tend to be more expensive and/or more difficult to handle but they may last for ten years or more.

Figure 7-3. Cost (USD) per km (left) and metres of line per kg (right) for braided polypropylene string/rope. At the time of writing this cost about USD 2.00 +/- 0.50/kg in S.E. Asia.



2. Suspension materials

In some situations suspension materials may be obtained for the cost of the labor that is used to collect them. In other cases the equivalent of several hundred USD may be spent to suspend each km of line. On average line suspension costs run on the order of 10-30 USD/km.

3. Anchoring systems

Some anchor materials may be obtained for the cost of collection labor. In other cases anchor costs may be as much as tens of USD/km.

4. Real estate

In most SEAsian regions farm sites are made available to local farmers with little or no rental charge. In other regions (e.g. India) farm concession areas are leased to users by government agencies.

5. Shelter and post-harvest treatment (PHT) structures

Costs of shelter and structures vary widely. In most tropical regions substantial shelters and drying areas can be constructed for a few thousand USD. Investments may become considerable if equipment and structures are installed for drying, washing or chemically treating the crop or for bagging and baling the crop.

6. Vessels & vehicles

The types of canoes typically used for tending farms usually cost about USD 100-300 each. The cost of large service and carrier vessels or vehicles can run to tens of thousands of USD but these are usually supplied by firms that perform collection, trading and processing value-chain functions.

7. Energy & handling equipment

Most family farms have little or no energy or handling equipment. Some may have a small generator costing a few hundred USD. Like large vehicles and vessels major handling equipment is generally supplied by firms that perform the collection, trading and processing functions.

Usage of materials for farm habitat construction can lead to negative environmental impacts. Injudicious cutting of mangroves and pollution of sea shores with plastic debris are two notable impacts to guard against.

7.5. Variable costs for eucheuma seaplant farms

Variable labor is the main cost of farm operation. Since most farms are family businesses labor is usually compensated by a share in farm proceeds.

1. Attaching propagules to substrate

Plate 7-6. The most labor intensive aspect of eucheuma seaplant cultivation is generally the attachment of individual propagules ("cuttings" or "seedlings") to pieces of string (lines). On average 3-4 hours/day are spent tying propagules to lines.

2. Maintaining crops & suspension/anchoring systems

Plate 7-7. Successful eucheuma seaplant farmers spend several hours daily in gear maintenance and crop care. The most commonly performed tasks are shaking of plants to remove sediment, weed removal, replacement of floats and ropes and re-attachment of loose propagules.

3. Harvesting and post-harvest treatment (PHT)

Stripping plants from lines is a simple task but drying the crop can be laborious and time consuming, especially during wet seasons when the crop must be repeatedly spread out and placed under cover.

Plate 7-8. It is during PHT that many "trading games" are played. Much of the interplay among buyers and sellers involves actions that are taken during drying, crop treatment and packing.

Hired labor is used by some farmers.

In some cases an amount equal to about 50-100% of local minimum wage is paid as wages or on a piecework basis to farm labor (e.g. about USD 1-2 per day in S.E. Asia). Hired labor is commonly used for attaching plants to substrate, for preparation of substrate and for PHT chores.

The bottom line...

SEAPlantNet farmer surveys have indicated that the average family farm produces about 0.8-2.5 mt of dried eucheuma seaplants per month. Two,, three or more family members may spend 3-4 hours each (about 6-12 man-hours) per day on farming activities or about 180-360 man-hours/month. This equates to production ranging from 2.8 -11 kg of dried crop per man-hour. At a farm gate price of USD 0.50/kg this gives an hourly gross farm income of about USD 1.40 -5.50/man-hour.

Productivity varies between regions and among farms but eucheuma seaplant farmers generally seem to make returns to labor that are far above local minimum wages.

7.6. Example financial estimates for a simple family farm

Table 7-3. It was assumed that a farm is capable of producing one metric ton of dry cottonii per month with these parameters:

1. Uses floating line or raft system (bamboo or plastic-buoys).
2. Propagule size 100 grams; spaced 20 cm apart.
3. Therefore needs propagule base-stock of 4,300 kg (live)
4. Requires 8.6 km of line; lines spaced 20 cm apart.
5. Cropping cycle 42 days; specific growth rate 2.5%/day ; Wet:dry ratio 8:1

Startup material costs in USD:

	Item	Unit	Total
1.	120 kg (8.6 km) of 5 mm polypropylene line	5	600
2.	4,300 kg of live propagules	0.2	860
3.	50 kg anchor & spreader ropes & "loop" twine	5	250
4.	180 cement anchors	4	720
5.	700 plastic floats (1 litre size) or equivalent	0.5	350
6.	One canoe	300	300
7.	Miscellaneous tools and equipment	n/a	320
8.	Work shed & tarpaulins for drying	600	600
Totals		**USD**	**4,000**

Amortisation table:

	Item	Cost	years	USD/mt
1.	Suspension lines & other cordage	850	2	35.00
2.	Anchors	720	10	6.00
3.	Floats	350	5	6.00
4.	Canoe	300	10	2.50
5.	Miscellaneous tools and equipment	320	2	1.00
6.	Work shed & tarpaulins for drying	600	10	5.00
	Totals		USD	55.50

Labor and seed-stock:

Assume that start-up labor is invested as "sweat equity" and that payment for propagules is a one-time charge (recycling of propagules is calculated into the yields). Note that "labor" and "time" can be traded for propagule cost if farmers propagate their own seed-stock.

Earnings:

Based on prices typical of the past five years farmers would receive about 400-500 USD/dry ton gross or about 340-440 USD/dry ton net of amortised material costs.

Typical production levels and incomes:

Recent farmer surveys in the Philippines, Malaysia and Indonesia (Gan, 2004) indicated that monthly production by full-time farmers was typically in the range of 0.8-2.5 mt. Thus lower-yield family farms would return as little as 300 USD/mo to labor and the more productive farms would return as much as 1,250 USD/mo to labor. A few farms produced five or more tons per month and could earn twice this amount.

Financing options for family farms:

1. Self financing within the family is common especially for farm expansion.

2. Collectors or traders commonly advance funds for farm development.

3. Micro-financing programs sponsored by banks, government agencies (GA) or non-governmental organisations (NGO) are in place in several regions of S.E. Asia.

4. Grant funds are periodically available from GA or NGO.

5. Firms sometimes undertake incentive programs that contribute funding or materials do the more productive farm units.