An Illustrated Review on Cultivation and Life History of Agronomically Important Seaplants

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1 author:

Felix Bast
Central University of Punjab

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Felix Bast

Centre for Biosciences, Central University of Punjab, Bathinda, Punjab, 151001, India

Telephone: +91 86991 36536; Fax: +91 164 2430586

Email: felix.bast@cup.ac.in

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Abstract

Seaplants (a better alternative to the misnomer "Seaweeds"), by all means, are "future plants"; they have been projected as the future viand for ever-increasing human populations, viable and sustainable source for biofuel without disturbing global food scenario, as potential candidates for carbon capture and sequestration that is considered as a practical remedy for global warming, and they have a number of pharmaceutical, industrial and biotechnological applications. However, information on its cultivation methods or life history remain obscure to a majority of marine botanists. While life histories of seaweeds have traditionally been an exotic topic for specialists-language of which is ciphered with scientific jargons incomprehensible to general scientific audience, its agronomy had been a trade secret for coastal communities in East Asian countries, especially Japan, the Philippines and Indonesia. In this up-to-date illustrated review, current scientific understanding on the life-histories of agronomically pertinent seaweeds are presented in a fashion akin to popular science journalism with an overview of major coastal and offshore seaweed mariculture techniques, presented with the aid of clear-to-understand illustrations. Also discussed in this report are recent advances in the algal natural products; including uses in hydrocolloid and pharmaceutical industries, Integrated Multi Trophic Aquaculture, energy production, environmental impacts of the seafarming and its counter measures, before concluding with an overview of future research avenues.

Keywords

Seaweed Cultivation; Seaplant; Mariculture; Integrated Muti-Trophic Aquaculture; Edible Alga; Marine Agronomy; Algal Natural Product

Introduction

Seaweeds are heterogeneous group of marine plants; comprising many of the primitive non-vascular lineages, known as algae. Of the nine algal lineages in the six-kingdom model of the tree of life (Cavalier-Smith 2004, 1998), three have macroscopic taxa. These are conventionally grouped into green (Chlorophyta), red (Rhodophyta) and brown algae (Heterokontophyta) depending on the type of pigment being expressed. However, the external color is not a synapomorphic character and most of these groups are polyphyletic in nature. Despite the overwhelming importance of seaweed, the very name is a misnomer. Weed is a plant-or even a person- that is unsightly, useless and causes injury to others; while seaweeds are crucial primary producers for which the entire ocean biota depend on and indeed very useful for the humans-as we will see in this paper. To avoid wrong connotations, it is suggested to refer seaweeds as "seaplant"-a more accurate lexicological portrayal of this heterogeneous group of macroscopic marine non-vascular plants. Conventionally, microscopic aquatic plants be referred as algae (marine or limnetic based upon the habitat). This term "seaplant" is therefore adopted in the subsequent discussion to refer plants popularly referred as seaweeds.

Seaplant farming, or macroalgal mariculture, refers to the cultivation of marine macroalgae for the support of various industries including food, hydrocolloid, pharmaceutical and nutraceutical, biotechnology, cosmetic, textile, paper, energy and so on. In the wake of competing demands during the world food crisis, seaplants have attracted much attention lately from the researchers and environmentalists alike as a future food source. Multitude of environmental crises such as human population explosion –that lead to the shortage and overexploitation of cultivable land, chemical and genetic pollutions due to yield-oriented agricultural practices, and ever increasing shortage of freshwater have been encouraging farming of edible seaplants as a sustainable alternative to the conventional agriculture. Farming of seaplants for food has a number of definitive advantages. Seaplants can be readily cultivated nearshore or offshore without fertilizers and drugs and its cultivation do not require land or freshwater resources. However, issues such as non-acceptance of seaplants in the existing culinary cultures of many countries and nonpalatability of a number of seaplant taxa remains to be effectively addressed before its universal acceptance as a future food can be achieved. People from countries that have geographic proximity to the sea and long cost line, such as Japan, North and South Koreas, the Philippines, Scandinavia, Ireland and Chile, are more accustomed to the taste of seaplants to have them in their routine diet. The history of seaplant utilization as food has been extensively reviewed (Chapman 1950; Boylan 1971) and it is apparent that edible seaplant cultivation in East Asia, especially Japan, is at least two thousand years old. A critical analysis of medieval Japanese *Waka*- a form of short poetry suggests that the word seaplant stood as an imagery to express emotions such as love, compassion and sensuality in ancient Japan (Bast 2013). Seaplant occupies a prime position in traditional Japanese culinary (Nisizawa et al. 1987). With increasing number of reports validating the projection of seaplants as a healthier alternative to the conventional terrestrial plants for dieting, prevention of diseases and longevity, its wider acceptance is likely in the near future (Ozaki et al. 2007).

Marine agronomy

It was only a few decades ago that the concepts of modern agronomy have started to find applications in the field of seaplant farming (Doty 1979; Santelices 1999), however improvement of the existing farming methods have been very minimal for the last four decades or so. Manipulating factors contributing to the site fertility is often impractical due to the continuous nature of ocean. Therefore, we are limited to choose right, fertile site before the farming and continue until nutrients get exhausted, rather than attempting to alter site to make it more fertile. Current understanding of the farm fertility suggests far more viable factors than the four originally hypothesized; viz., temperature, water quality, water motion and light. These include additional abiotic factors such as availability of suitable substrata, pollution and eutrophication, and biotic factors such as biodiversity, presence or absence of grazing vectors, pathogens or epiphytes, and presence of invasive species. Recent findings suggest that role of biodiversity in providing stability for the established seaplant beds is much more than previously thought (Stachowicz et al. 2008; Boyer et al. 2009). Seaplant polyculture is found to be significantly more productive than monoculture, perhaps due to factors such as facilitation and differential use of macrohabitats in heterogeneous environment. A small-scale experiment in which herbivore density have been manipulated in tide pool suggest that seaplant species evenness and primary productivity were increased by the presence of snails, as they preferentially consumed otherwise dominant less-productive seaplants (Altieri et al. 2009). Another factor is UV-B irradiation that affects spatial and functional structure of seaplant communities in coastal environments (Bischof et al. 2007).

One significant difference from the land plants is that there is no alternative to the seeds in seaplants, making its long term storage and propagation significantly complicated. Seaplants have complicated life cycles and maintaining unialgal cultures in laboratories, although laborious, is often the method of choice. Some progresses have been made recently in these lines, such as development of vegetative propagation protocols from cells and protoplast and thereby using these as seed stock (Polne-Fuller and Gibor 1986; Hernández-González et al. 2007) and selection of improved and/or disease resistant strains by selective breeding or hybridization by protoplast fusion (Cheney 1990). Recent advances in seaplant micropropagation techniques have been reviewed by (Reddy et al. 2008). Selective breeding and genetic improvement of the cultivars for increased yield, flavor etc. have been successfully applied in several high-value seaplant genera, including *Saccharina* (Yan et al. 2006), *Undaria* and *Porphyra* (Chaoyuan and Guangheng 1987; Dai et al. 1993). Attempts by genetic engineering have also been done, whereby transferring biolistic gene to spores of several commercially important seaweed genera, taking advantage of the life cycle (Qin et al. 2010).

In an agronomic point of view, there are two types of seaplants; viz., clonal and non-clonal (Santelices 1999). Clonal seaplants have ability to propagate by fragmentation and therefore its cultivation is less laborious. Typically, these are farmed in one-step, i.e., tying fragments to the ropes and nets and its installation in the farm site. During each successive harvesting, a small piece of fragment is allowed to remain attached with the nets so that the thalli get regenerated in the next growth season. This farming method do not involve nursery-rearing of the seedlings and do not demand expensive infrastructural support or expertise and this might be the reason for its immense popularity in developing countries including China, the Philippines and Chile. Examples include *Eucheuma*, *Kappaphycus*, *Sargassum* and *Caulerpa*. In contrary, non-clonal (unitary) seaplants do not have fragmentation ability and the only way to cultivate them is by completing the life cycle during each growth season. Farming is multistep and it typically involves *in-vitro* fertilization and nursery rearing of young seedlings on the nets, before its installation in farm sites. Examples include several high-value seaplants such as *Porphyra*, *Gracillaria*, *Saccharina*, *Undaria*, *Monostroma* and *Ulva*. Cultivation techniques for clonal and non-clonal seaplants are illustrated in Fig. 1.

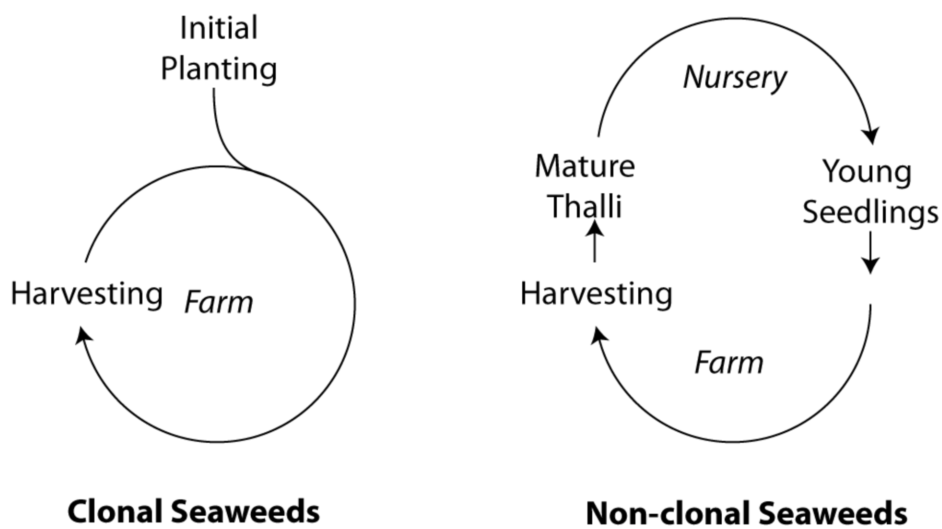

Fig. 1. Summary of farming method employed for clonal and non-clonal seaplants.

There are four basic types of agronomic methods widely employed in commercial seaplant cultivation; Floating raft method, Semi-floating raft method, Off-bottom (fixed bottom) method and Bottom planting method. In floating raft method (Fig. 2A), rafts are floated by means of buoys (styroform or even inflated PET bottles or coconut husks) installed in nearshore or offshore sites, such that they are floating all the time irrespective of the tides. The frame of the raft can be either synthetic material or wood, such as bamboo poles. Seaplant is cultivated in nets made of nylon or other materials (such as polyethylene or coir), which is interwoven in the raft frame. In this method, rafts are held in place via deadweight mooring, to prevent its drifting. A variant of this method is known as "longline method", in which seaplants are grown in the main rope that is floated via buoys installed at every 4-5 meters and ends fixed via deadweight mooring. Floating raft or longine is the method of choice for kelps (*Saccharina*, *Undaria*) and employed for Eucheumoid seaplants (*Eucheuma* and *Kappaphycus*) and *Sargassum*.

In semi-floating raft method (Fig 2B), rafts with seaplant cultivation nets are attached with top ends of the poles. Bottom ends of the poles have a tripod-like structure and are free, not anchored into the shoal. As in the floating raft method, rafts are attached to an array of buoys such that the system gets floated during high tide. During low tides, tripod-like structure of the poles firmly touches the shoal and this makes raft with cultivation nets get exposed. This method is therefore a combination of floating raft and fixed net methods and guarantees good sunlight irradiance at all the times. This method is used extensively for the commercial farming of seaplants that require periodic exposure to the air, such as *Porphyra*, *Monostroma* and *Ulva.*

In off-bottom method (Fig 2C), nets are hung between the poles that are fixed to the shoal. Poles of suitable heights are chosen so that at high tides, the nets are immersed, while at low tides, nets get exposed. As the nets are immersed in body of water at high tides, light irradiance is a limiting factor. This method therefore demands an appropriate site with sandy bottom and sufficient sunlight. As the farm being easily accessible at low tides, one potential problem is attack from intertidal epiphytes and grazers. Sites with minimal natural flora of these pests need to be chosen for the successful implementation. Seaplants that require periodic drying such as *Porphyra*, *Monostroma* and *Ulva* are extensively cultivated by this low-cost method. In a variant of this method, nets are installed such a way to have subtidal environment; i.e., nets are lower than water level during low tides. This method has been widely used in developing countries to substitute more expensive floating-raft for the cultivation of Eucheumoid seaplants.

In bottom planting method (Fig 2D), seaplants are cultivated on substratum placed directly on the shoal. This method is typically employed in areas where low level of water remains at low tides such that the planting can be performed without diving. Bottom planting assures immerse of seaplant at all the times and is performed for such benthic genera with thin corticated cylindrical thalli (*Gracillaria* and *Sarcodiotheca*) as well as those with creeping stolon (*Caulerpa*).

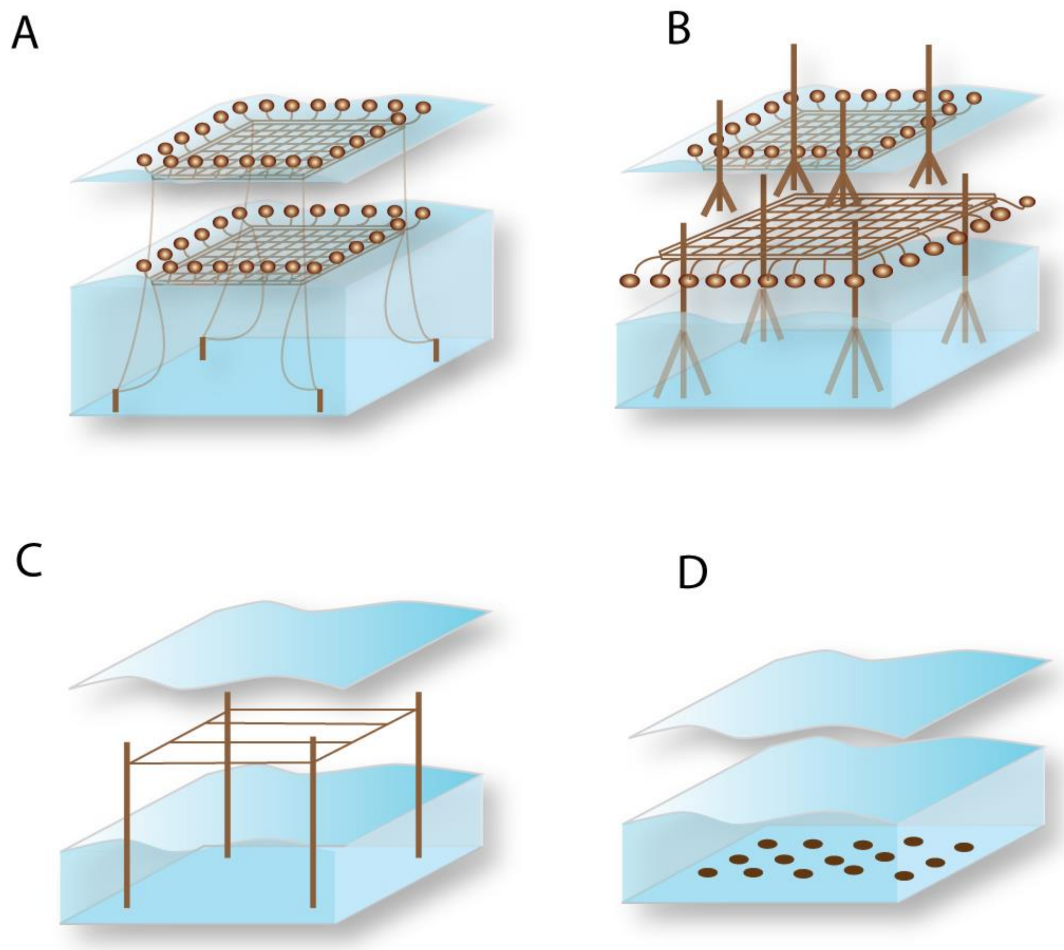

Fig. 2. Four basic types of seaplant agronomic methods. A. Floating raft in deep sea with deadweight mooring. Raft is floated all the time. B. Semi-floating raft in shallow water. Raft is floated at high tides but gets exposed during low tides. C. Off bottom in shallow water. Nets get immersed in high tide and exposed in low tide. D. Bottom planting in shallow water. Immersed at all the times. Water levels at high-tide are shown above low tide in all illustrations.

Extent of seaplant farming

While seaplants can grow in rocky coastlines in all the seven continents throughout the year and many of the human civilizations have been utilized them for hundreds of centuries, commercial farming has not yet been spread in many countries. For a long time, seaplant farming had been limited to East and Southeast Asia, while Northern Europeans harvested natural stocks. It was only less than a century ago that the commercial farming of seaplants for hydrocolloid industry have spread from Asia to South America and Africa, while Europeans and North Americans still have not started wide-scale farming.

In 2008, around 15.8 million tons wet weight of seaplants with estimated market value of USD 7.4 million were farmed worldwide (FAO 2010). Production figures for intensively cultivated taxa are presented in Fig. 3. Comparing with world production of fish and other aquacultured animals- which is roughly 52.5 million tons in the same year, seaplant farming still remains a minor aquaculture industry. The FAO data also indicate consistent increase in the seaplant farming sector since 1970 with an annual growth rate of 7.7 per cent.

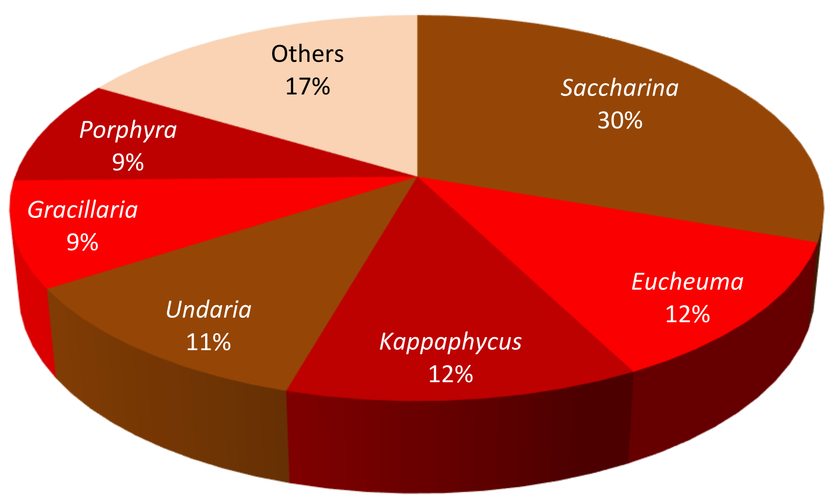

Fig. 3. Worldwide production of seaplants in 2008, with contribution of major genera (FAO 2010)

China is the world leader in seaplant farming with almost 63 per cent of the total seaplant production coming from that country. Southeast Asian countries (Indonesia and the Philippines) farmed mostly Eucheumoid seaplants for carrageenan industry. In contrast, almost all of the East Asian countries (China, North and South Koreas and Japan) farmed seaplants that are used as food. East and Southeast Asia- taken together, accounts for almost 99.6 per cent of the world seaplant production. This indicates that contribution of the seaplant farming industry outside Asia to the world seaplant farming is virtually meager. Outside Asia, Chile was the major seaplant farming country with 21,700 tones wet weight of seaplants farmed in 2008. Africa produced 14 700 tones with South Africa, Tanzania and Madagascar as the leading countries. In South Africa, seaplants are farmed mainly for feed supply to the abalone industry, while in Tanzania and Madagascar, main seaplant farmed are Eucheumoid genera (*Eucheuma* and *Kappaphycus*) to support carrageenan industry.

Major seaplant taxa farmed

There are about 200 species of seaplants commercially utilized worldwide, of which about 10 genera are farmed intensively (Zemke-White and Ohno 1999). As described already, cultivation methods largely depend upon the life cycle of the taxa being cultivated and therefore understanding the life cycle is an important aspect of the seaplant farming. Detailed life cycle and cultivation information with suitable illustrations for the major farmed seaplant taxa is summarized here for the first time. Because a comprehensive treatment of all of the cultivated taxa is beyond the scope of this review, only top ten species are included:

Red seaplants: *Porphyra*, *Kappaphycus*, *Eucheuma* and *Gracilaria.*

Brown seaplants: *Saccharina*, *Undaria* and *Sargassum*.

Green seaplants: *Monostroma*, *Ulva* and *Caulerpa*.

Porphyra (Bangiales)

Porphyra is the most expensive seaplant taxa worldwide owing to the high commercial demand of its product *Nori* (laver). This seaplant is found on intertidal splash zones of subtropical and temperate habitats. Life cycle is haplodiplontic (Fig. 4); with macroscopic monostromatic gametophyte stage consisting of haploid foliose (blade-like) thalli. In many species, the gametophytic thalli are monoecious (i.e., having both male and female reproductive structures in one plant). Fertilization occurs when spermatia, the male gametes, lands on the blades and produce a tube that penetrate cell wall of the female gametes. After fertilization, repeated mitotic divisions of zygotes result in packets of diploid zygotospores (carpospores) within the blade phase. Female gametes in some species also undergo process of parthenogenesis (Nelson et al. 1999).

Originally it was thought that this genera has only one life cycle stage, i.e. the blade-like gametophytes, however, microscopic sporophyte conchocelis stage-that was previously thought to be a separate taxa- was discovered in 1949 which dramatized farming techniques (Drew 1949). This diploid filamentous stage develops on calcareous substrata such as shells of barnacles or mussels when zygotospores are released and deposit upon them. Meiosis within conchosporangium results in haploid conchospores (tetraspores) that develops into foliose gametophyte to complete the life cycle. A number of molecular studies indicate that the *Porphyra* might contain polyphyletic assemblage of taxa that have converged to monostromatic foliose morphology (Stiller and Waaland 1993). This genus is reportedly containing the most primitive plastid genome ever found (Reith and Munholland 1993).

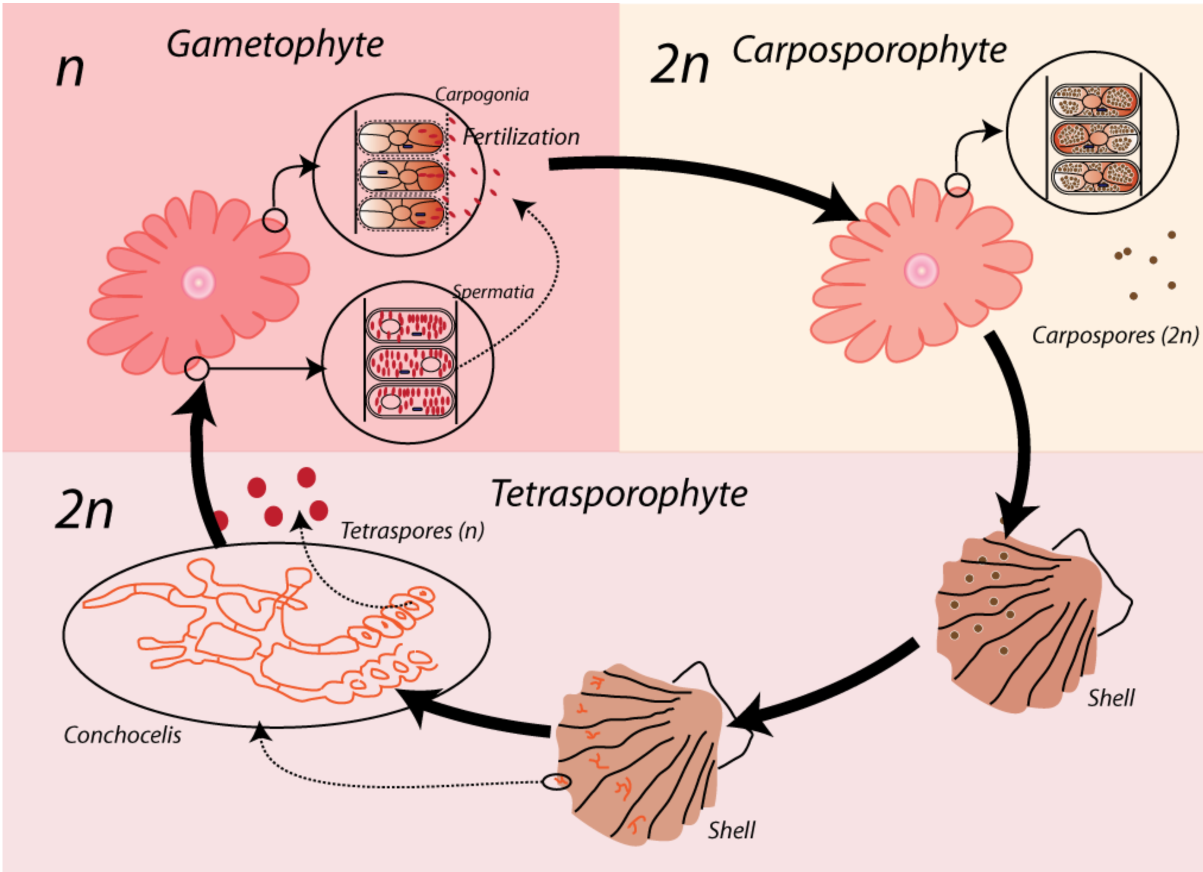

Fig. 4. Summary of *Porphyra* life cycle.

Porphyra is a non-clonal type of seaplant and therefore successive regeneration of the thallus from fragments is not possible, necessitating appropriate seed culture prior to each farming season. Conchocelis-filaments are reared in lab on the shells and other calcareous substratum and conchospores are released using controlled temperature and light intensity. Released conchospores are seeded into the cultivation nylon nets that are brought to the farm in the beginning of each season. There are two types of cultivation methods for this seaplant; viz., off-bottom and semi-floating raft. In the off bottom system, cultivation nets are hung between poles fixed in shallow water such that nets experience intertidal habitat (expose to air during ebb tides). One limitation of this method is that it is restricted to the inner regions of bays, with shallow, sandy bottoms. In semi-floating method, nets are tied on floating frames with long poles so that during ebb tides, poles keep the net exposed to air. The thalli loose approximately 90% of the moisture during daytime exposure-during which they are also exposed to intense sunlight, UV and temperature stress, making it one of the highly stress-tolerant plants ever known (Blouin et al. 2010). Experimental cultivation of this seaplant in tanks (Israel et al. 2007) as well as its vegetative propagation (Polne-Fuller et al. 1984) have been reported, although these have never been commercially implemented.

2.4.2 Kappaphycus (Gigartinales)

Kappaphycus is cultivated in many countries for the production of kappa-carrageenan. This seaplant is often found in reef flats and edges from 1m to 15m depth loosely attached with coral reefs. *Kappaphycus* requires high light levels, warm seawater and a high degree of water motion for the successful cultivation (Glenn and Doty 1990). The lifecycle is triphasic, consists of dioecious gametophyte (N), carposporophyte (2N) and tetrasporophyte (2N) phases, similar to that of *Eucheuma* (Refer Fig. 5 for a schematic illustration of sexual life cycle). Gametophytic thalli is erect filamentous with cylindrical branches that are heavily cartilaginous. Spermatia and carpogonium are produced by male and female thallus, respectively. Gametes fertilize within terminal parts of the female thalli (trichogyne) to form diploid carposporophyte, which subsequently produces diploid carpospores. Repeated mitotic divisions in the carpospores results in the formation of tetrasporophyte, and subsequent meiotic divisions within tetrasporangia results in the haploid tetraspores. Released tetraspores develop to respective gametophytes to complete the life cycle.

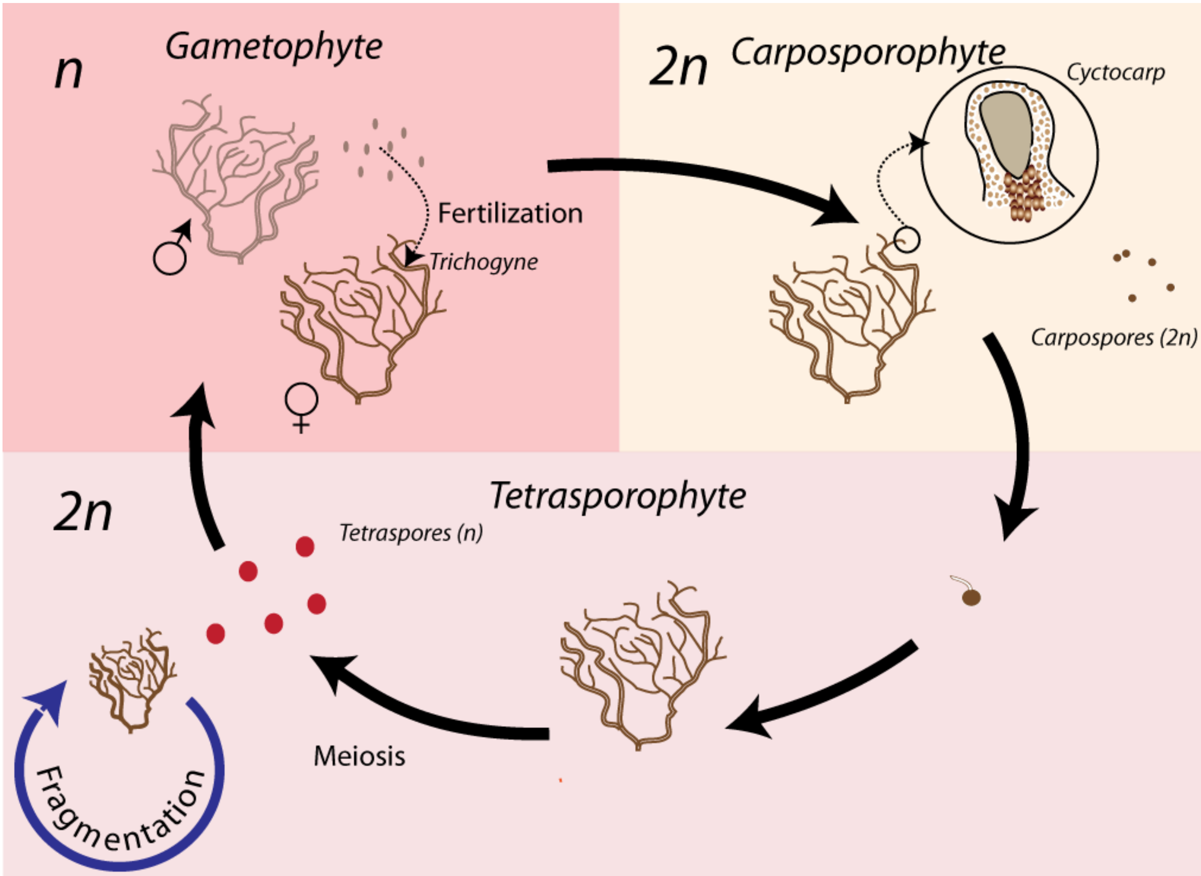

Fig. 5. Summary of *Kappaphycus* and *Eucheuma* life cycles.

One of the significant breakthroughs in the commercial farming of this genus is the understanding that the thalli need not undergo the sexual lifecycle or spore production for crop propagation. Fragments as small as 0.5 cm attached to the ropes are capable of developing to complete thalli. Farming techniques of clonal propagation are therefore successfully employed in this seaplant. A fixed off-bottom monoline method is used for the cultivation of this and other Eucheumoid seaplants. Bamboo/wooden sticks are anchored in rows 10 meter apart and 1 meter wide and ends of adjacent sticks in two rows are joined by nylon lines. Seedlings, each about 50g wet weight, are tied to these lines about 30 cm apart. When seedlings reach 1kg (in roughly two months), the plants are harvested (Hurtado-Ponce et al. 1996; Ohno et al. 1994; Trono 1999).

Eucheuma (Gigartinales)

Together with *Kappaphycus* and *Chondrus*, *Eucheuma* is cultivated in many countries for the production of carrageenan. Morphology varies significantly with the habitat, but in general thalli consists of multiaxial filaments with rigid corticated cylindrical branches. The habitat is typically between low tide mark and upper subtidal zone of reef system. The life cycle is already described triphasic polysiphonia-scheme as illustrated in Fig. 5 (Kylin 1956), common for many red algae of Gigartinales including *Kappaphycus*. Adequate, moderate to slow, water movement seems a major factor for the growth of this seaplant (Doty et al. 1986). Sufficient sunlight of about irradiance levels of 500-900 $\mu Em^{-2}S^{-1}$ is also a factor to be considered while choosing the farming site. Most popular cultivation method is fixed off-bottom monoline, as described for the *Kappaphycus*. When this method is prohibited due to space constraints etc, floating methods have also been successfully used in many farms. In floating method, seedlings are tied to the nylon lines and the lines are tied to floating rafts of bamboo/wooden sticks that are attached to Styrofoam buoys or empty plastic bottles. The buoys are firmly placed in site via mooring ropes. *Eucheuma* is clonal seaplant and repeated harvesting from the same plant is therefore possible, bypassing need for complicated nursery seed-culturing steps. Algal epiphytism and grazing are reported to be major problems for the commercial *Eucheuma* cultivation (Hurtado-Ponce 1990).

Gracilaria (Gracilariales)

The red agaophyte *Gracilaria* accounts for almost 50% of the world Agar production. Habitat is flat and wide subtidal areas with hard or sandy bottoms. This species grows best in areas where nitrogen content is between 50-100 mg/m^3 and certain amount of freshwater is letting in. Frond morphology widely varies in different species, from erect to prostrate and flattened; generally it is thin corticated cylindrical. Like other red algae described, *Gracilaria* have a triphasic Polysiphonia-scheme life cycle (Fig. 6). Tetrasporophytic and gametophytic phases of this alga are isomorphic free-living and carposorophyte phase is a parasite of female gametophyte. After fertilization, distinct cystocarps appear as hemispherical lumps throughout the thallus of female gametophytes. Cystocarps release diploid carpospores (2n) that develops into tetrasporophyte (2n) plants, isomorphic to the gametophytes. Tetrasporophytes undergo meiosis and release tetraspores (n) that develops into respective haploid dioecious gametophyte plants.

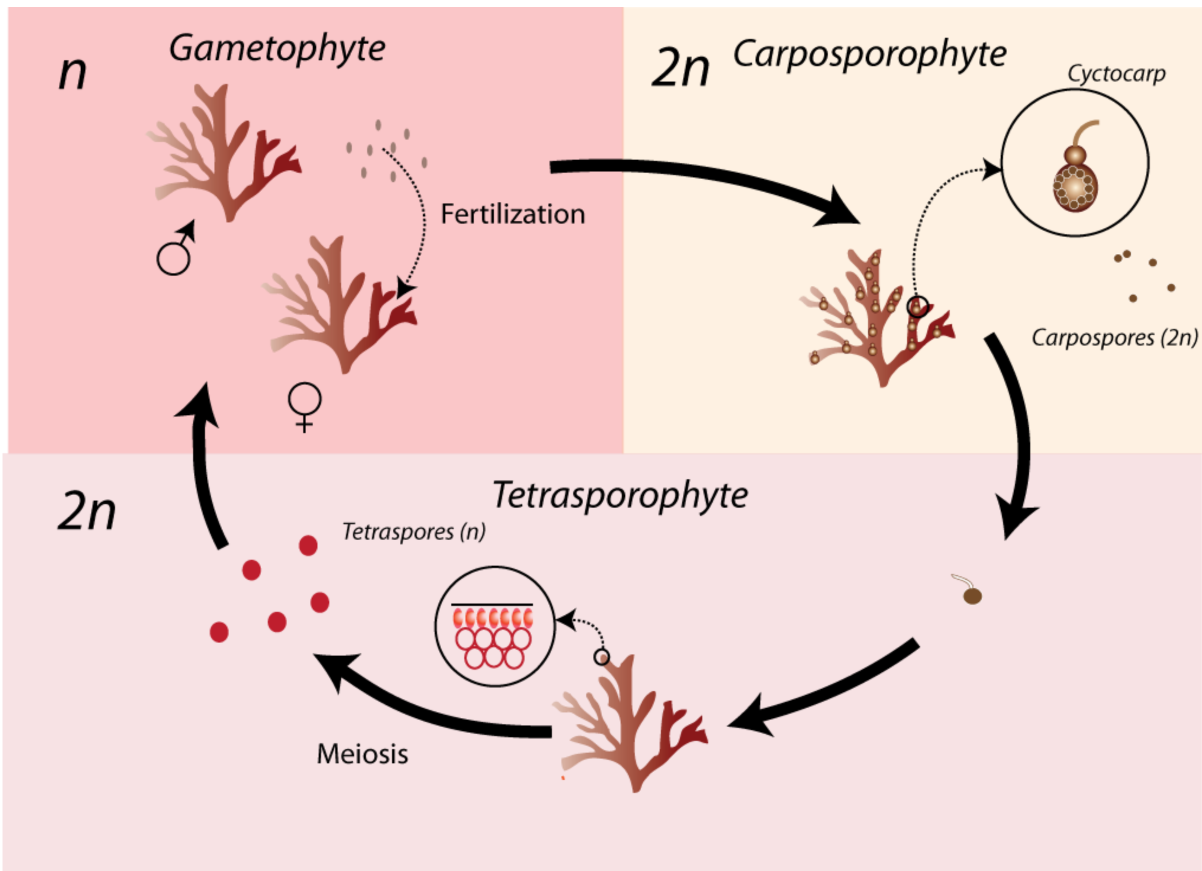

Fig. 6. Summary of *Gracilaria* life cycle.

As a non-clonal type of seaplant, seedling culture is required prior to each farming season. Plants with numerous cystocarps/tetrasporangium are selected and carpospores/tetraspores are allowed to be released by sun-drying the fronds, cutting to small pieces and placing them in seawater. Released spores will be allowed to sink on the suitable substratum like pebbles or shells (scattering sporeling culture method), farming nets (net culture method) or polypropylene ropes (raft culture method) where they get germinated. Upon germination, substrata are taken and installed in the farm. Alternatively, spore-filled water at optimum density can be collected and sprayed on the substrata at the shoal during ebb tides. Generally few glass slides are also placed along with the substrata before spraying, and microscopically observed next day to ensure adequate spore density. It is normally farmed in 50 cm^2 quadrants with 30 cm space in between and allowed to reach 50-100cm in length within 3-4 months before harvesting can be made. Some preliminary studies have conducted in farming of this alga by vegetative fragment cultivation in floating cages, but the yield was very low (Hurtado-Ponce 1990). Various open pond/ outdoor tank culture methods have also been developed to increase the yield (Dawes 1995), however, algal epiphytism remains a serious issue (Fletcher 1995).

Saccharina (Laminariales)

The brown seaplant genus *Saccharina* (Kelp/Kombu) consists of some 40 species commercially farmed in various countries for human consumption, extraction of hydrocolloid alginate and renal vasodilator, mannitol. This is the most intensively farmed seaplant genera around the world in terms of wet weight harvested. Most of the commercially cultivated species of this genus was earlier grouped under *Laminaria* until a recent molecular phylogenetics study conducted in the family Laminariales that resurrected genus *Saccharina* Stackhouse to include kelps other than the type species *Laminaria digitata* (Lane et al. 2006). According to various sources *Saccharina* is the most intensely cultivated seaplant genera in terms of dry-weight. Along with *Porphyra*, *Undaria* and *Gracilaria*, this seaplant constitutes almost 93% of the worldwide seaplant cultivation (Zemke-White and Ohno 1999; Lüning and Pang 2003). One unique use of this seaplant is the centuries-old practice of cervix dilation (“ripening”) by inserting dried *Saccharina* tents and allowing it to expand, to assist in the labor and abortions (Jonasson 1984). Habitat of this seaplant is shallow subtidal cold waters of temperate regions, with southern limit of 36° N. This genus comprises dioecious species having diplohaploid lifecycle (Fig. 7), with dominant macroscopic phase being diploid sporophyte. Upon fertility, distal-medial portions of the blades develop numerous "sori"-aggregation of unilocular sporangia. Diflagellate zoospores settle and germinate to haploid microscopic, isomorphic gametophytes. Gametophytes release diflagellate gamets that fuses to form zygotes and germination of which results in the sporophyte generation, completing the life cycle.

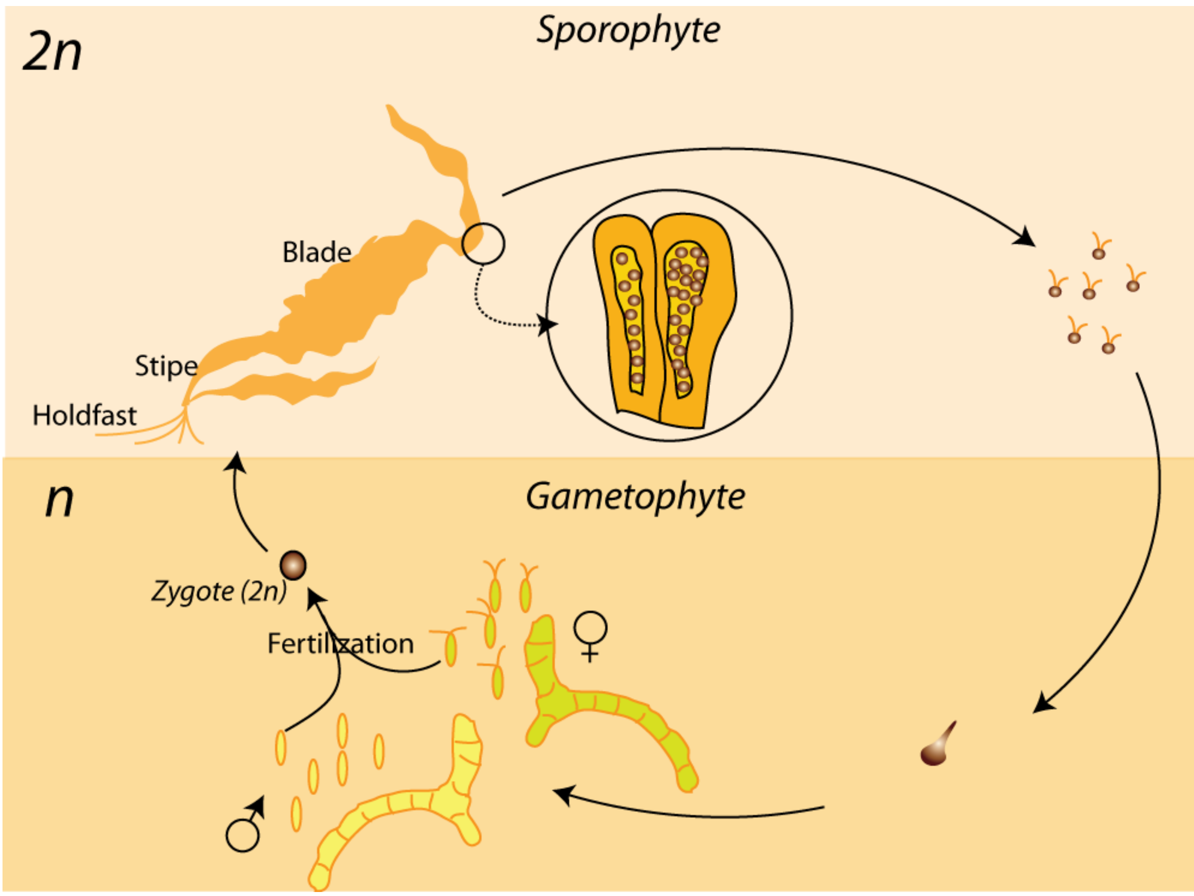

Fig. 7. Summary of *Saccharina* life cycle.

Saccharina is non-clonal seaplant and seedlings need to be reared before transplantation in each farming season. Rearing of seedlings is typically done in indoor facility, before it can be transplanted to the farm. Plants with numerous sori are collected and dried to facilitate zoospore release and released zoospores are allowed to deposit on suitable substrata, such as ropes or bamboo sticks. Germination of zoospore and its further development result in mature microscopic gametophyte plants in 2-3 months. Upon gamete release and fertilization, zygotes are deposited on the same substratum and are allowed to germinate and develop for another couple of months till young sporophyte plants reach 15-20 cm. These are then transplanted to thick kelp-culture ropes or rafts when seawater temperature falls below 18° C. These ropes or rafts are installed in shallow coastal areas via buoys tied with mooring ropes. Sporophyte plants are grown hung on the ropes throughout winter and spring, lasting 6-8 months- before a harvest can be made. New methods like gametophyte clone generation (Li et al. 1999) and photolithotrophic cultivation (Qi and Rorrer 1995) have been developed to hasten sporeling culture, although utilization of these in commercial farms have not yet been reported. There are several reports on strain improvement through cross-breeding attempts (Zhang et al. 2007; Li et al. 2008) perhaps owing to its high commercial value.

Undaria (Laminariales)

The brown seaplant *Undaria* is farmed principally in East Asia for the food produce *wakame*. Habitat is shallow subtidal temperate coast with moderate to high wave exposure and there are some progress in understanding its population ecology (Thornber et al. 2004). *Undaria* is native to East Asia (China, Korea and Japan) and got introduced elsewhere predominantly by ship hull fouling (Thornber et al. 2004). This seaplant shares similar life cycle and cultivation strategies to closely related genera *Saccharina*. Life cycle is diplohaplontic alternation (Fig. 8) with dominant phase being macroscopic sporophyte that is being harvested. Zoospores are produced from the sporophylls on the basal part of the stipe. Upon the release of zoospores, sporophytes wither and disintegrate. Released zoospores get settled on appropriate substrata like shells, bamboo sticks etc. and germinate to microscopic male and female gametophytes. Male and female gametes released by respective gametophytes fuses to form zygotes that germinate and develop into macroscopic sporophyte generation to complete the life cycle.

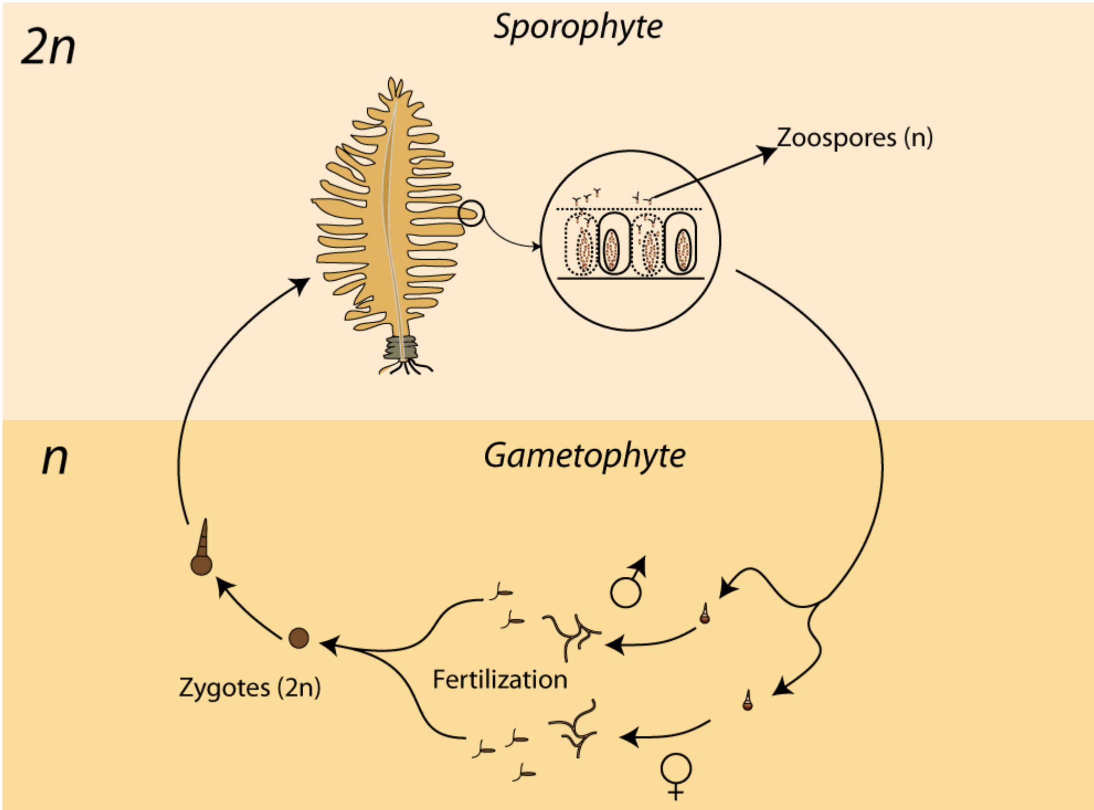

Fig. 8. Summary of *Undaria* life cycle.

Farming of this non-clonal seaplant involves seedling culture and rearing in indoor ponds. Zoospores are collected from matured plants by briefly drying the plants, keeping at dark for 3-4 hours and re-introduction in seawater with intense light supply. Released zoospores are collected by wooden spore collectors with ropes and gametophytes are reared by hanging them in tank filled with seawater. Growth of gametophytes, release and fertilization of gametes, and its germination to microscopic sporophytes are all done in these spore collectors. Once the sporelings reach size of 1mm, the spore collectors are introduced to the farm site and wound over ropes of the floating raft structure and grown in a similar fashion as described for *Saccharina*. There are some reports on the sporophyte regeneration from protoplasts (Matsumura et al. 2001), cryopreservation of the gametophytic cells (Kuwano et al. 2004) and gametophyte culture in photobioreactors (Xu et al. 2002) however none had been widely utilized in the industrial cultivation. Diseases, pathogens and parasites affecting *Undaria* farms have been recently reviewed (Neill et al. 2010).

Sargassum (Fucales)

Members of the brown algal genus *Sargassum* have been cultivated in many parts of the world, predominantly as food produce *Hijiki* (*S. fusiforme* = *Hizikia fusiformis*) in East Asia (Korea and Japan). *Sargassum* is cultivated or its natural stocks are harvested in India as an alginophyte (Kalimuthu et al. 1991). *Sargassum fusiforme* is a rich source of fucoxanthin-a major antioxidant (Yan et al. 1999). This seaplant has slender, long fronds separated from one another and this is one distinct morphological feature from other *Sargassum* species. Habitat is eulittoral to sublittoral shallow coastal zones in subtropics to temperate ecosystems. This alga is endemic to north-west coast of the Pacific ocean and is thought to have introduced elsewhere (Nisizawa et al. 1987). Life cycle information of this dioecious alga is almost non-existent, but considering its taxonomic affiliation in genus *Sargassum*, it is thought to be monobiontic and diplontic (Fig 9). The dominant phase which is harvested is diploid gametophyte. Male and female gametophytes develop respective receptacles in which haploid gametes are produced by meiosis. Female gametes are not broadcasted into the surrounding seawater unlike male gametes. The fertilization is thought to be isogamous within female receptacles, followed by germination of the diploid zygotes within the receptacle itself. Germlings with the mucilaginous coat get released from the receptacle and settle on suitable substrata near the parent plant where it grows back to male and female gametophytes, completing the life cycle. Reproductive maturation in this seaplant is found to be associated with the latitudinal temperature gradient, with populations growing in subtropic regions mature earlier than that in temperate (Nisizawa et al. 1987). The holdfasts of gametophytes can regenerate new seedlings (therefore gametophyte generation is often referred as sporophyte) and this clonal fragmentation ability has been widely utilized for its commercial cultivation. Most of the farms are in South Korea where floating raft culture technique, similar to that in kelp farming, is employed. There are some attempts for the cultivation of zygote-derived seedlings in raceway tanks, however these have not yet been implemented for the commercial farming (Pang et al. 2008).

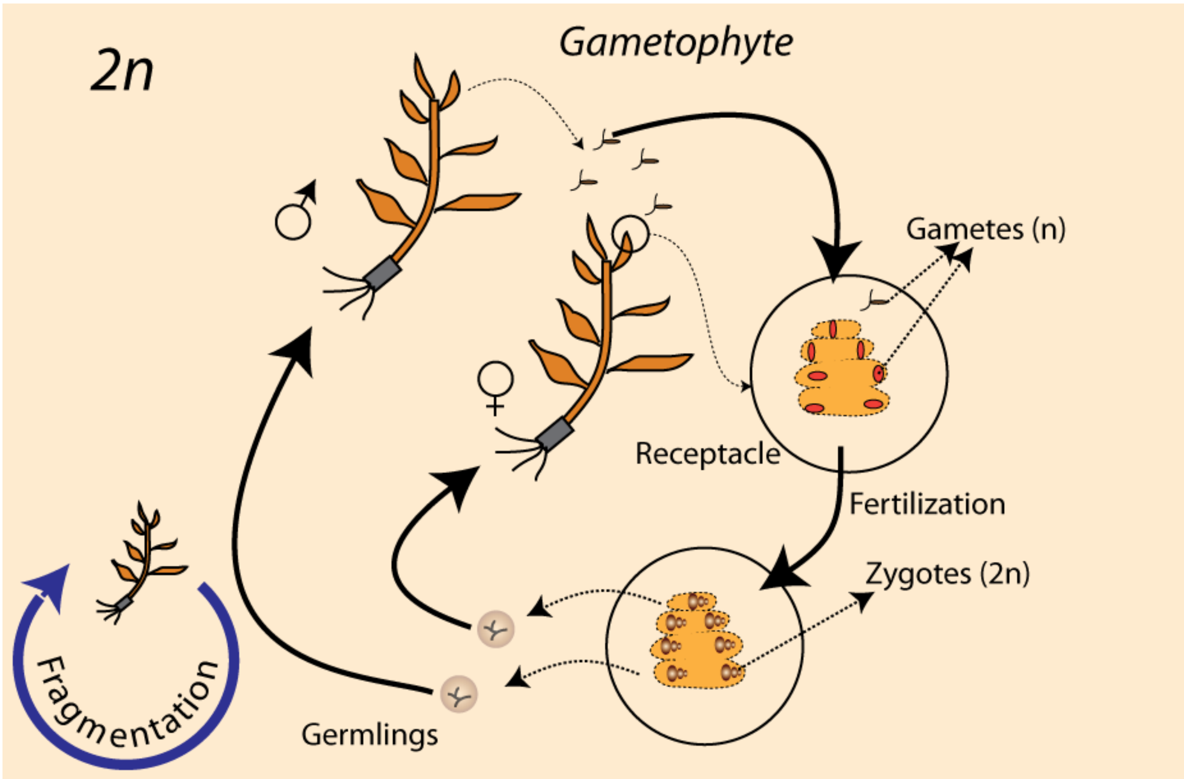

Fig. 9. Summary of *Sargassum fusiforme* life cycles.

Monostroma (Ulotrichales)

Among green seaplants, *Monostroma kuroshiensis* Bast is the most intensely cultivated genus, constituting about 90% of the total green algal cultivation (Nisizawa et al. 1987), almost exclusively for the Japanese food produce *hitoegusa*. Habitat is typically intertidal rocks of semi-exposed coasts in subtropical to temperate ecosystems, with most of the occurrences are reported either from the Scandinavia or from West Pacific. The frond is blade-like with eponymous one-cell thickness and therefore it is also known as “Slender sea-lettuce”. This is a well-studied seaplant genus with information such as ecophysiology (Bast 2010), habitat-dependent seasonality of its growth pattern and sex-ratio (Bast et al. 2009a; Bast et al. 2009c), gametangial ontogeny (Bast and Okuda 2010) and phylogenetics (Bast 2011) have been reported. Lifecycle is haplodiploid alternation (Fig. 10), with dominant, macroscopic phase being haploid dioecious gametophyte. Upon maturity, apical parts of the fronds get matured and phototactic biflagellate gametes get released. Fertilization is anisogamous and settled zygotes mature into microscopic, spherical diploid *Codiolum*-sporophytes. After 3-4 months of growth, sporophytes get matured and quadriflagellate zoospores are produced. Settled zoospores germinate and mature into respective gametophytes, thus completing life cycle. A monomorphic asexual lifecycle in this genus have also been reported from the population in Japan (Bast et al. 2009b).

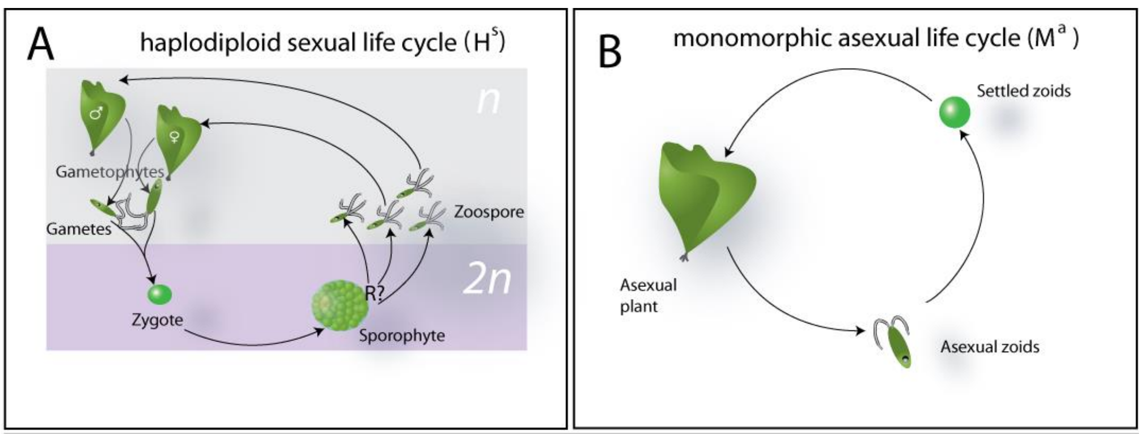

Fig. 10. Summary of *Monostroma kuroshiensis* life cycles.

Algae belonging to this complex have been used for human consumption in East Asia- especially in Japan- since time immemorial. As a non-clonal type of seaplant, appropriate seedling culture is needed before each farming season. Seeding method used in the cultivation can either be natural (*e.g.*, Ise Bay) or artificial (*e.g.*, Shimanto Estuary, Kochi Prefecture). In the natural seeding method, plants derived from the naturally deposited zoospores on the culture nets are harvested. On the other hand, in the artificial seeding method a large quantity of zygotes –as obtained from *in vitro* fertilization of isolated gametes by the end of growth period- are grown throughout the summer. The resulting *Codiolum*-sporophytes are then treated with high intensity of light to induce zoospore release. Culture nets are immersed in the concentrated zoospore solution under dark conditions to facilitate successful attachment of released zoospores on the nets. These "seeded" nets are subsequently installed in the attached fabrication of wooden sticks in the coastal waters and the height of nets are adjusted such as to provide adequate immerse-in and drying-out effects with each tidal range. Upon reaching the highest size, thalli are harvested and processed.

Ulva (Ulvales)

Green distromatic seaplants of the genus *Ulva* (Sea lettuce) are commercially cultivated in East Asia for the food produce *Aonori*. Seaplant having resemblance to lettuce are in fact *U. fasciata*, *U. lactuca* etc.- that are distromatic blades, while commercially cultivated species include *U. prolifera* (=*Enteromorpha prolifera*) and *U. intestinalis* that are tubular with walls of the tube one cell thick. Habitat is upper eulittoral zones of subtropics, especially on river mouths where diurnal fluctuation in salinity is high. This species is the main causative agent of green tides, including the one that happened along the shores of Qingdao in 2008 during Beijing Olympics (Liu et al. 2010). This is a dioecious species having diplohaplontic lifecycle (Fig. 11) with isomorphic gametophytic and sporophytic stages. Thalli are coarsely filamentous that can be branched or unbranched and have disc-like holdfasts developed from basal cells that attach firmly on suitable substratum like pebbles or rocks. Upon maturity, apical region of the haploid gametophytes changes color to orange-yellow (males) or yellow-green (females) and release biflagellate gametes. Fertilization can be isogamic or anisogamic. Zygotes attaches to suitable substrata where it germinates and develop into diploid sporophyte generation. Apical parts of the sporophytes mature in a similar fashion to that of gametophytes and produces quadriflagellate zoospores by meiosis. Released zoospores settle on substratum and germinate to respective gametophytes, completing the life cycle.

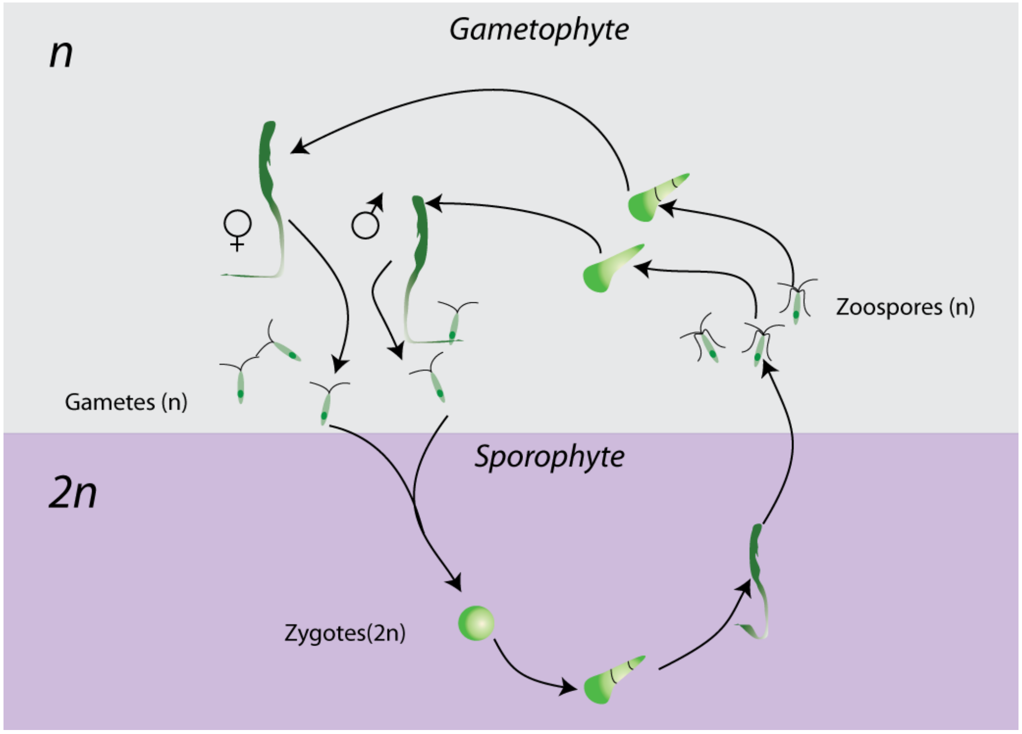

Fig. 11. Summary of *Ulva* life cycle.

Cultivation method is similar to that of *Monostroma*. In natural seeding method, rope nets are submerged in places where this alga grows naturally. Once the germination is detected, the nets are taken and brought to the farm. In artificial seeding method, matured thalli are collected and gamete release is induced with a combination of brief drying, followed by floating in seawater with intense illumination. Fragmenting the thalli is found to be an effective way to induce gametogenesis and is used for its artificial seeding (Dan et al. 1997). Released gametes are allowed to get settled on culture nets by providing dark conditions. Once germinated, these nets are taken to the farm. Nets with germinated algae are cultivated on poles fixed in shallow, calm areas of ocean or in estuaries, such that the nets periodically get exposed to air with each low-tide. Tank cultivation using deep sea-water, the so called "germling cluster method" have also been developed, although not widely implemented for the commercial cultivation (Hiraoka and Oka 2008). Information on its phylogenetics (Hayden and Waaland 2004) and phylogeography (Shimada et al. 2009) are known making it one of the well-studied green algal lineages. While reproduction by fragmentation is not known, settled vegetative fragments of this seaplant was found to be a source for the succession of green tides (Zhang et al. 2011).

Caulerpa (Bryopsidales)

While better known to be invasive seaplant wreaking havoc to the Mediterranean marine biodiversity, *Caulerpa* is also the third most cultivated green seaplant. At least two species of edible *Caulerpa* (Sea grapes) are cultivated in many parts of East Asia, *C. lentillifera* and *C. racemosa*. There are many reports on the invasiveness of this genus, especially that by *C. taxifolia* in the Mediterranean (Jousson et al. 1998). Habitat for *C. lentillifera* and *C. racemosa* are muddy or rocky seabed of shallow tropical coastal areas. Morphology is siphonous (coenocytic) with horizontally branched stolon. Almost entire length of stolon axes is covered by many short ramuli. Each ramulus consists of a globular tip with 1-3mm in diameter and a short connecting stalk. Stalk joins to a distinct constriction on the base of globular tip. Not much information on the life cycle is known for this algae, but considering its association in bryopsidales, the safe bet would be monomorphic sexual, as illustrated in Fig. 12 (Goldstein Ph 1970). Gametophytes are diploid and monoecious. Upon maturity, gametophytes give rise to biflagellate gametes. During this process, entire protoplast migrates to periphery and integrates into gametes, thus making the thalli appear briefly white before fully disintegrating. Gamete release is synchronized, with simultaneous release of vast numbers of male and female gametes, released as green clouds typically at early morning, a process known as “mass spawning” (Clifton 1997). Fertilization is anisogamous (Miyamura 2005). The zygote settles down on appropriate substrata and germinates back to gametophyte generation, thus completing the life cycle (Ohba et al. 1992). Asexual reproduction by fragmentation is well-known, especially in invasive populations (Wright 2005). Genetically, most of the natural *Caulerpa* populations show little variation and therefore predominant mode of reproduction in nature might be fragmentation.

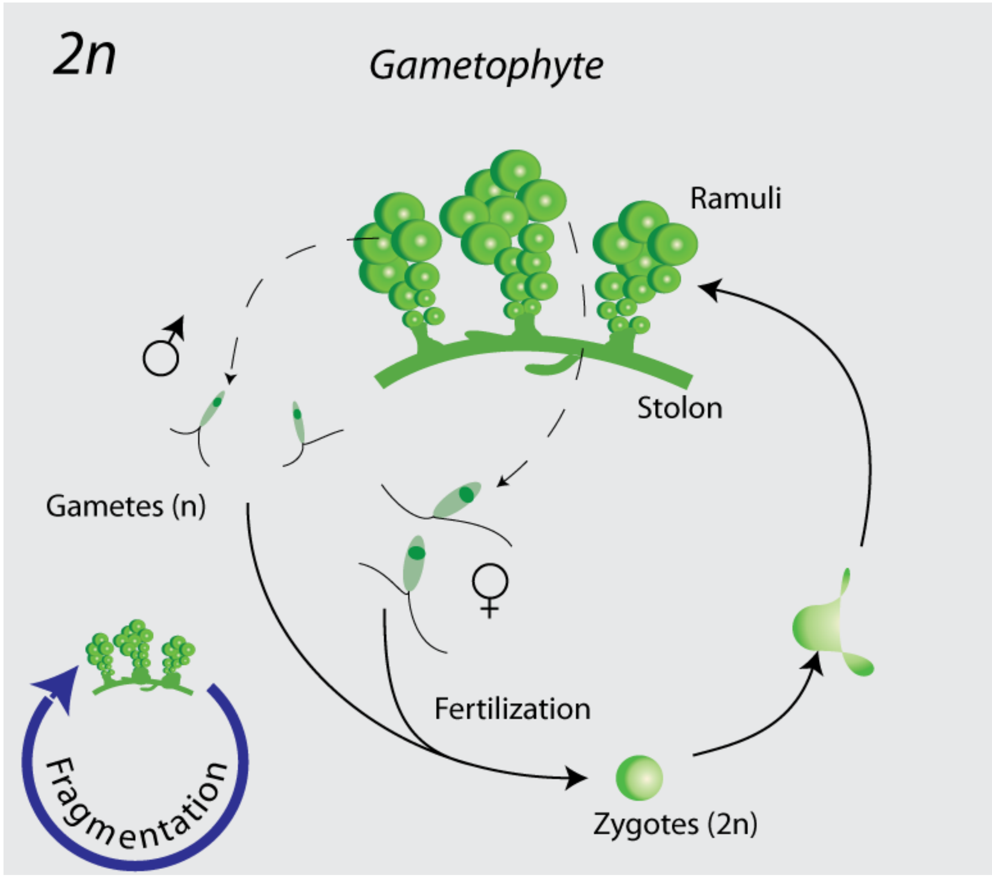

Fig. 12. Summary of *Caulerpa* life cycles.

Caulerpa is cultivated in ponds and lagoons in the Philippines and Okinawa where the fronds are eaten fresh as an ingredient in salads. Bottom planting method is employed in which rhizoidal thalli are planted by hand in upper 2 cm of the muddy shoal (Horstmann 1983). Ponds and lagoons are usually shallow, around 0.5 meters depth, with muddy bottom. This method ensures an all the time immersed environment suitable for this benthic seaplant. While harvesting, about a quarter thalli are left as a seed for the next harvest. Some attempts have been made to initiate land culture of this seaplant using deep sea water (Sudo and Araki 2004), although high cost associated with this method seems to be a major limitation.

Utilization of seaplants

As a food

Historically and in terms of market value, seaplants are primarily utilized as a food. Edible seaplant industries are mostly cottage type with small scale harvesting and primitive modes of processing like rack-drying akin to papermaking (Naylor 1976). A larger demand for the seaplant products branded “traditionally cultivated and processed” might be one of the reasons behind lesser industrial expansion of this sector in Japan. The industry is often controlled by local fishermen’s unions and seaplant brands are known after the respective places of production. For example, the famous Shimanto nori (*Monostroma kuroshiensis*) is cultivated by fishermen’s union at Shimanto city, Kochi Prefecture, Japan. While seaplants are rarely-if any- consumed raw, the edible seaplants are sometimes referred as “sea vegetables” as an analogy to the land vegetables. Known by the latter name, there is a renewed interest in its culinary usage in the West (Lewallen and Lewallen 1996; Novaczek and Athy 2001).

One of the most renowned seaplant food products is *Nori* (Laver), the dried monostromatic blades of the red seaplant *Porphyra.* Nori is the primary constituent in Sushi, the famous Japanese dish which is getting popular throughout the world. Due to high demand, most of the modern research and development for breed selection, improvement of the yield, texture etc. are concentrated on this product. Characteristic flowery aroma of Nori- which is the major factor for its wide appeal- has been attributed to compounds derived from carotenoids (Winterhalter and Rouseff 2002). Recent research suggest that the reason why only people from Japanese descent can digest sulphated polysaccharides of Nori is the horizontal transfer of genes coding for porphyranases- which is crucial in its digestion- from the marine bacteria *Zobellia galactanivorans* to the gut bacteria *Bacteroides plebeius* (Hehemann et al. 2010). While Nori contains high Vitamin B12, the iodine content is quite low compared with other edible seaplants (Watanabe et al. 1999) and therefore, this is the seaplant of choice for thyroid patients. There are several other red seaplants as well commonly used as food produces. Ogonori, made from *Gracilaria* spp (Gracilariales) is a common Japanese produce used as an ingredient in cold summer noodles

(Sōmen). Dulse or creathnach, a popular Irish snack, is made from dried *Palmaria palmata* (Palmariales). Chilean produce Quechua (*Durvillaea antarctica*) is an ingredient in traditional stews. The Irish Moss (*Chondrus crispus*) is a very popular seaplant produce in America and Caribbean Islands, where this is sold as snack or as an ingredient in various beverages. Jellified form of the Irish Moss used to be one of the popular confectionary in Ireland where it is known as Cairgean, before its usage have gone down significantly in recent times (Kenicer et al. 2000).

A number of edible seaplant products are made from brown seaplants. *Kombu* is a processed food product from the brown seaplant *Saccharina japonica* (Sugarware or “Kelp”, Laminariales). The dried *Kombu* is one of the main ingredients of *dashi*, the Japanese soup stock. *Kombu* is also extensively pickled (*su-kombu*) and used as jam (*kombu tsukudani*). Yet another well-known product is *kombu-cha*, the green “tea” made with *kombu*. The food produce *Arame* is made from *Ecklonia bicyclis* (Laminariales). Having a distinct taste, the dried and pulverized *Arame* is added into a number of dishes, including soups and appetizers. There are several other kelp species commonly used to make food products in the West. One such example is Dabberlocks, a popular western food produce made from *Alaria esculenta* (Laminariales). Fingerware is a popular Irish seaplant produce made from *Laminaria digitata*. Dried *Fucus vesiculosus*, known as bladderwrack, is an additive and flavoring agent used in various European food items. Popular South American produce Carola is made from dried and processed *Callophyllis variegate*. *Wakame* is yet another major seaplant product made from brown seaplant *Undaria Pinnatifida*. Boiled *wakame* is a major ingredient of Japanese miso soup served as a breakfast staple along with rice. Several reports demonstrate anticancerous (Funahashi et al. 1999), antihypertensive (Sato et al. 2002) and antiobesity (Maeda et al. 2005) properties of this product, making it a popular nutraceutical choice. The seaplant produce *Hijiki* is made from the brown seaplant *Sargassum fusiforme*. *Hijiki* is mainly used in Japanese cuisine as an ingredient in salads and soups. As a part of macrobiotic food movement, *Hijiki* got immense popularity in the west during 1990s (McCarty 1996). Due to high arsenic content, the *Hijiki* is often extensively washed and socked prior to cooking (Hanaoka et al. 2001). The popular Hawaiian produce Limu-Kala, an ingredient in soups, is made from dried *Sargassum echinocarpum* (Hanaoka et al. 2001). Mozuku is an Okinawan food produce made from

Cladosiphon okamuranus and is used in salads. Mozuku contains more Fucoidan-a sulphated polysaccharide with many biological properties- than any other seaplant and therefore it is used as a nutritional supplement (Kawamoto et al. 2006).

A plenty of food products are made from green seaplants as well. Perhaps *Hitoegusa,* the monostromatic green alga (*Monostroma latissimum*), is the most important of all edible green seaplants in Japan in terms of economy and quantity of production. Market value of this seaplant is the highest among all the cultivated seaplants with 1 kg costing about USD 30 (Zemke-White and Ohno 1999). Harvested *Hitoegusa* is boiled down in soy sauce to make a jam-like product (tsukudani-nori) while dried sheets (hoshi-nori) are used as sushi wraps. Other popular products are roasted (yaki-nori) and seasoned (ajitsuke-nori) *Hitoegusa*. The Japanese seaplant produce, *aonori* or *aosanori* is made from dried *Ulva prolifera*. Aonori is used as a seasoned produce and sprinkled over boiled rice to serve. Other edible green seaplants include Sea Grapes (*Caulerpa lentillifera*), Sea Lettuce (*Ulva lactuca*) and Gutweed (*Ulva intestinalis*).

Hydrocolloid Industry

Hydrocolloids are polysaccharide colloids dispersed in water and therefore having a gel-like constituency. Several of the seaplant-derived hydrocolloids are used as an ingredient in various food items like jellies, deserts and confectionary. Examples of hydrocolloids include Agar, Alginate and Carrageenan. Agar is a polysaccharide of galactose sugar extracted from several genera of red seaplants-collectively referred as agarophytes- that include *Gelidium* and *Gracilaria*. Exploiting its gelling and emulsifying abilities, agar is used in various ways such as constituent of biological culture media (Agar plate), as a vegetarian gelatin in various food items like jellies, puddings and deserts, toy manufacturing, as an impression material in dentistry and as electrochemical salt bridges. Further chemical refinement of less-ionic fractions of agars produces a highly refined seaplant product Agarose. Agarose is extensively utilized in biotechnology industry as a solid phase in Gel Electrophoresis and therefore played a crucial role in the biotechnological revolution of last century (Renn 1990).

Carrageenan, a sulphated polysaccharide made up of galactose-related monomers, is another seaplant-derived hydrocolloid extensively used in food industry. Carrageenan is extracted from hot water suspensions of red seaplants *Eucheuma*, *Chondrus* and *Kappaphycus* (together, these are known as carrageenophytes). Along with agar, carrageenan is also used as a gelling and emulsifying agent in food and is often used as a substitute for gelatin by the vegans. Carrageenans have a plethora of uses; as an additive in various food items, toothpaste, shampoo, personal lubricants, marbling, shoe polish and as an excipient in tablets to name a few. Low molecular weight degraded carrageenans have been reported to be causing colon ulcers in experimental animals (Watt and Marcus 1971). Although natural carrageenan generally regarded as safe for human consumption, degraded carrageenan has been classified as a possible human carcinogen by the International Agency for Research on Cancer (IARC). It has been found that carrageenan induces cell arrest in human epithelial cells *in-vitro* suggesting it might have role in normal human intestinal pathology (Bhattacharyya et al. 2008). Recently, carrageenan has been demonstrated to inhibit genital transmission of Human Papillomavirus (HPV) infections in mouse, warranting further research to utilize it for human STD prevention and cure (Roberts et al. 2007). Although *in-vitro* studies showed effective anti-HIV properties, largest human trials so far conducted in South Africa showed that carrageenan-based vaginal gel, Carraguard®, fails to protect women against HIV (Cohen 2008).

Alginate, salts of alginic acid-an anionic polysaccharide, is yet another seaplant-derived hydrocolloid widely used in many different ways. This is commercially extracted from brown seaplant genera *Laminaria*, *Macrocystis* and *Ascophyllum*. The process of extraction include precipitation of salts with hot sodium bicarbonate and further filtration of sodium salts (McHugh 1987). Alginates are also used in various industries, such as impression-making material in dentistry, prosthetics, as an appetite suppressant in weight loss industry and waterproofing and fireproofing agent in textiles. Calcium alginate (CA) microbeads have been developed recently which can deliver plasmid DNAs and yeast artificial chromosomes to animal and plant cells (Higashi et al. 2004) and Plant Growth Promoting Bacteria (PGPBs) to wet and dry seeds (Bashan et al. 2002), further accelerating its demand in biotechnology industry.

Other natural products

There are a number of seaplant natural products other than what are mentioned above. This includes use of seaplant biomass as a fertilizer and soil conditioner for agriculture and horticulture industry (Aitken and Senn 1965). Recent studies indicate issues with its widespread uses, including arsenic biotransformation and accumulation and therefore care must be must be taken while choosing taxa and/or habitat to use as a fertilizer (Zhao et al. 2010). Uses of seaplant extracts as a plant growth enhancer in agriculture have been reviewed in (Craigie 2010). Addition of low concentrations of commercial kelp extract (Kelpack®) has been proven to be beneficial in agriculture and aquaculture (Robertson-Andersson et al. 2006). Nutritional and pharmaceutical potentials of a number of seaplant natural products have been comprehensively reviewed (Fitton 2003; Abdussalam 1990; Bocanegra et al. 2009; Smit 2004). Seaplant-derived bioactive substances that have multitude of biomedical applications include fucoidans, lectins, sulphated polysaccharides and aplysiatoxins. Seaplant derived substances that are used as vermifuges and insecticides include kainoids, terpenes, diterpenes (Crenulacetal C used in pearl cultivation), sesquiterpenes and polyhalogenated monoterpenes. Another high-value seaplant natural product is phycoerythrins extracted from red seaplants. Phycoerythrins, especially R-Phycoerythrin from *Porphyra*, is extensively used as fluorophore in applications such as immunofluorescence and Fluorescence-Activated Cell Sorting (Kronick and Grossman 1983; Glazer 1994). Seaplant carbon-based carbon nanotubes have recently been developed as a nanotexturing agent for high power supercapacitors (Raymundo Piñero et al. 2011). Ever-growing technology sector is expected to facilitate finding more unique uses for seaplants and development of seaplant-based natural products.

Integrated Multi-Trophic Aquaculture (IMTA)

Fed aquaculture, especially that for shrimps and finfish, generate enormous amounts of nutrient waste that causes multitude of environmental problems in aquaculture fields. Altered nutrient loading in coastal areas lead to problems associated with eutrophication, such as enhanced sediment metabolism, sulphide accumulation and sulphate reduction, high nitrogen and phosphorous influx, turbidity, anoxia, acidification and so on (Troell and Berg 1997). Fed aquaculture has long been regarded as the least sustainable and energy inefficient form of farming practices. In order to mitigate the nutrient wastes generated during fed aquaculture, field of Integrated Multi-Trophic Aquaculture (IMTA) have developed which is centred on the idea of co-cultivating organic extractors (e.g. shellfish/herbivorous fish) and inorganic extractors (seaplants) in the fed aquaculture. While simple polyculture implies culture of different organisms belonging to same trophic level, IMTA involves co-farming of organisms belonging to various trophic levels and considers each contributor's ecological systems and services.

Seaplants in IMTA act as biofilters by assimilating excess inorganic waste and thereby contributing in the bioremediation. Seaplants have been widely integrated in various IMTA systems around the world and its utility have been extensively reviewed (Chopin et al. 2001; Neori et al. 2004). Many of the studies conducted in close circulation systems conclude that seaplants take-up large quantities of nutrients and convert them to seaplant biomass, in addition to improving other water quality parameters. Biofiltration of nitrogenous wastes from recirculating abalone mariculture system using seaplants have been recently demonstrated to be outperforming bacterial biofilms (Cahill et al. 2010). An increasing number of studies suggests "green-tide" seaplants such as *Cladophora*, *Chaetomorpha* and *Ulva*, can be effectively integrated to the tropical pond-based aquaculture for bioremediation (de Paula Silva et al. 2008) as well as for seaplant farming (Yokoyama and Ishihi 2010; Bolton et al. 2009; Msuya and Neori 2010), thus making them attractive candidates for IMTA systems. Shrimps grown with *Ulva* in outdoor tanks have demonstrated lower artificial feed requirements and efficient assimilation of *Ulva* carotenoids, thus making IMTA a sustainable and healthier alternative to traditional aquaculture (Cruz-Suárez et al. 2010).

Energy production and Carbon Capture and Sequestration

The world is turning to the seaplant farming to combat various environmental issues as well, energy crisis being one of them. With energy prices fluctuating widely amid diminishing fossil energy resources, there had been a recent surge in the research on the potential usage of algae as a renewable fuel source. Although algae fuel won't reduce atmospheric CO_2 level- as CO_2 fixed by the algae is returned to the atmosphere when the fuel is burned, it won't contribute in the introduction of new CO_2 as in the case of burning fossil fuels; i.e., they are "carbon neutral". Various extraction methods have been developed to harness lipids and its esterification into biodiesel, biogasoline etc., from algal biomass. biofuel production has traditionally been concentrated to few species of microalgae as the photosynthetic rate and oil content of microalgae appears to be significantly higher than that of seaplants (Bird and Benson 1987). However, high production cost for the complex microalgal cultivation systems like photobioreactors have incited a renewed interest in seaplants as a potential source. One method is to ferment seaplant biomass to bioethanol and then anaerobic digestion to biogas (Aizawa et al. 2007). A recent study describes the saccharification of Floating Residue-a surplus by-product of alginate extraction process- into to yeast-fermantable sugars for bioethanol production (Ge et al. 2011). A vast majority of seaplants that are currently utilized for energy production come from either harvesting the natural stock or by collecting the drifting biomass. Due to high demand, natural stocks of the seaplants have decreased significantly necessitating increased seaplant farming attempts (Bruton et al. 2009), especially with metabolically engineered seaplant strains that can produce high quantity of lipids (Rosenberg et al. 2008). Seaplant farming has also been proposed as the most viable way to facilitate Carbon Capture and Sequestration (CCS) for combating global warming (Smith 1981). Greenhouse gases mitigated during seaplant biomass production can be safely disposed, the so called "seaplant carbon sink". However recent *in-situ* experiments suggest that the process of using seaplant as global carbon sink may not be as effective as originally thought and might even have undesirable side effects (Dalton 2002).

Environmental impacts of seaplant farming practices

A number of studies have documented potential environmental issues associated with seaplant farming, although relatively far fewer comparing to that of fed-aquaculture. These can broadly be categorized as the following: 1) Habitat alterations 2) Shading effects and 3) Proliferation.

Introduced seaplants can change local community structure and thereby affecting ecological niche including food chain patterns. In one study, off-bottom farming of *Eucheuma* in Tanzania was found to be affecting growth of seagrass beds underneath and thereby disturbing ecosystem functioning and flow of ecological goods and services (Eklöf et al. 2006). As seagrass meadows are directly linked to productive coral reef ecosystem, changes in its cover might also have indirect consequences on coral reef ecological niche. Seaplant farming was documented to be causing changes in sedimentation patterns, with seabeds underneath the farms having finer sediments and lower organic carbon content (Eklöf et al. 2005). Seaplant farming is also associated with epiphytic abundances which might affect natural algal communities (Buschmann et al. 1996).

Rich canopy of seaplant farms definitely causes shading effects on the flora growing underneath. Altering local habitat due to this shading might have tremendous consequences, such as altered growth patterns of algal communities, differential migration patterns of meiobenthos and whereby structuring epipelagic ecological niche. Another potential effect would be on the sensitive reef ecosystem, alteration of the reef community structure due to algal encroachment will have far fetching impacts, as these harbor almost a quarter of all marine biota (Mulhall 2008). Excessive shading might lead to reduced growth of zooxanthellae- photosynthetic dinoflagellate symbionts of the corals that might lead to catastrophic bleaching of the entire coral reef system. Characterizing these effects on macroscale is warranted for effective policy making to implement sustainable seafarming practices.

Algal proliferation is fundamentally different from algal invasion. Proliferation implies spread of algae to the regions where it compete with existing flora, while invasion results in introduction to waters where it has no predator. Intentional introduction of seaplant, which might lead to proliferation, is an outcome of commercial seaplant farming. Before the advent of seaplant farming, almost all the introduced of alien seaplant communities can be attributed to maritime transport. While the introduction of *Undaria* in many parts of the world is largely due to shipping, introduction of *Kappaphycus* has been reported from many parts of the world where the seaplant is cultivated for carrageenan. Although documented risks from intentional introduction of alien seaplant are fewer than the unintentional introduction, seacrops as a group possesses some degree of threat to the local biota (Pickering et al. 2007). Environmental implications of proliferating seaplants have been recently reviewed in (Morand and Merceron 2009).

Conclusion

Although seaplants have been utilized in many civilizations around the world for hundreds of centuries, its cultivation has been very minimal outside Asia. Reason for disparities in seaplant farming can be attributed to differential treatment of seaplant as a food around the world, or simply lack of necessary impetus from the industry. Effective information dissemination about seaplant farming technologies and critical evaluation of unexplored geographical locations for the feasibility of seaplant farming are two commonsense strategies for the expansion of this sector. Seaplant agronomy is in infancy and more research is needed in such areas as sustainable and economically viable farming methods. Efforts should be taken to harness natural life cycle mechanisms like controlling gametangial maturation/gamete release and increasing growth rate of microscopic stages. Indoor tank cultivation methods developed for seaplants are impractical to be commercially implemented due to prohibitive costs. Large scale utilization of tissue culture and other micropropagation methods in seaplant farming might not be feasible at all. Strain improvements by hybridization or genetic engineering, although successfully implemented for many high-value seaplants, need to be expanded to other farmed taxa as well; improving carrageenan production by Eucheumoid seaplants being one of them. Native seaplant species which are fast growing, cultivable year round and having good market value need to be surveyed for the feasibility of utilizing them in both land-based and open water IMTA systems. Attention should be given to the location of farms and choice of farming methods for minimizing environmental impacts. Some straight forward measures would be avoiding locations with lush natural seagrass flora or coral reefs. Results from large scale seaplant-based energy harnessing projects, like Ocean Sunrise Project in Japan (Aizawa et al. 2007), are awaited to further clarify feasibility for integrating the seaplant farming in energy sector.

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References

Abdussalam S (1990) Drugs from seaweeds. Med Hypotheses 32 (1):33-35. doi:DOI:0306-9877(90)90064-L [pii]

Aitken J, Senn T (1965) Seaweed products as a fertilizer and soil conditioner for horticultural crops. Botanica Marina 8 (1):144-147

Aizawa M, Asaoka K, Atsumi M, Sakou T Seaweed Bioethanol Production in Japan-The Ocean Sunrise Project. In: Oceans 2007, 2007. IEEE, pp 1-5. doi:10.1109/OCEANS.2007.4449162

Altieri AH, Trussell GC, Ewanchuk PJ, Bernatchez G, Bracken MES, Sandin SA (2009) Consumers control diversity and functioning of a natural marine ecosystem. Plos One 4 (4):e5291

Bashan Y, Hernandez JP, Leyva LA, Bacilio M (2002) Alginate microbeads as inoculant carriers for plant growth-promoting bacteria. Biology and Fertility of Soils 35 (5):359-368

Bast F (2010) Comparative Ecophysiology and Phylogeography of Monostroma in Southern Japan., Kochi University, Kochi, Japan

Bast F (2011) *Monostroma*: the Jeweled Seaweed for Future. LAP LAMBERT Academic Publishing GmbH & Co. KG, 66121, Saarbrücken, Germany

Bast F (2013) Seaweeds in Japanese Culture: An analysis of medieval Waka poetry. The Phycologist 85:(accepted)

Bast F, Hiraoka M, Okuda K (2009a) Spatiotemporal Sex Ratios of a Dioecious Marine Green Alga: *Monostroma latissimum* (Kützing) Wittrock. International Journal on Algae 11 (2):141-150

Bast F, Okuda K (2010) Gametangial Ontogeny in Intertidal Green Alga: *Monostroma latissimum* (Kützing) Wittrock. International Journal of Plant Reproductive Biology 2 (1):11-15

Bast F, Shimada S, Hiraoka M, Okuda K (2009b) Asexual life history by biflagellate zoids in *Monostroma latissimum* (Ulotrichales). Aquatic Botany 91 (3):213-218

Bast F, Shimada S, Hiraoka M, Okuda K (2009c) Seasonality and thallus ontogeny of edible seaweed *Monostroma latissimum* (Kützing) Wittrock (Chlorophyta, Monostromataceae) from Tosa Bay, Kochi, Japan. Hydrobiologia 630 (1):161-167

Bhattacharyya S, Borthakur A, Dudeja PK, Tobacman JK (2008) Carrageenan induces cell cycle arrest in human intestinal epithelial cells in vitro. The Journal of nutrition 138 (3):469-475

Bird KT, Benson PH (1987) Seaweed cultivation for renewable resources. In: Developments in Aquaculture and Fisheries Science. p 381

Bischof K, Gomez I, Molis M, Hanelt D, Karsten U, Lüder U, Roleda MY, Zacher K, Wiencke C (2007) Ultraviolet radiation shapes seaweed communities. Life in Extreme Environments:187-212

Blouin NA, Brodie JA, Grossman AC, Xu P, Brawley SH (2010) *Porphyra*: a marine crop shaped by stress. Trends in plant science 16 (1):29-37

Bocanegra A, Bastida S, Benedi J, Rodenas S, Sanchez-Muniz FJ (2009) Characteristics and nutritional and cardiovascular-health properties of seaweeds. J Med Food 12 (2):236-258. doi:DOI:10.1089/jmf.2008.0151

Bolton J, Robertson-Andersson D, Shuuluka D, Kandjengo L (2009) Growing *Ulva* (Chlorophyta) in integrated systems as a commercial crop for abalone feed in South Africa: a SWOT analysis. Journal of applied phycology 21 (5):575-583

Boyer KE, Kertesz JS, Bruno JF (2009) Biodiversity effects on productivity and stability of marine macroalgal communities: the role of environmental context. Oikos 118 (7):1062-1072

Boylan HJ (1971) The commercial exploitation of seaweeds, with special reference to alginate manufacture. Planta Med 20 (2):178-180. doi:10.1055/s-0028-1099687

Bruton T, Lyons H, Lerat Y, Stanley M, Rasmussen MB (2009) A review of the potential of marine algae as a source of biofuel in Ireland. Sustainable Energy Ireland, Dublin
Buschmann AH, López DA, Medina A (1996) A review of the environmental effects and alternative production strategies of marine aquaculture in Chile. Aquacultural engineering 15 (6):397-421
Cahill PL, Hurd CL, Lokman M (2010) Keeping the water clean--Seaweed biofiltration outperforms traditional bacterial biofilms in recirculating aquaculture. Aquaculture 306 (1-4):153-159
Cavalier-Smith T (1998) A revised six-kingdom system of life. Biological reviews of the Cambridge Philosophical Society 73 (3):203-266
Cavalier-Smith T (2004) Only six kingdoms of life. Proceedings Biological sciences / The Royal Society 271 (1545):1251-1262. doi:10.1098/rspb.2004.2705
Chaoyuan W, Guangheng L (1987) Progress in the genetics and breeding of economic seaweeds in China. Hydrobiologia 151 (1):57-61
Chapman VJ (1950) Seaweeds and their uses. Methuen, London
Cheney DP (1990) Genetic improvement of seaweeds through protoplast fusion. Economically Important Marine Plants of the Atlantic: Their Biology and Cultivation Connecticut Sea Grant College Program, CT-SG-89-07, Groton, CT:15-26
Chopin T, Buschmann AH, Halling C, Troell M, Kautsky N, Neori A, Kraemer GP, Zertuche González JA, Yarish C, Neefus C (2001) Integrating seaweeds into marine aquaculture systems: a key toward sustainability. Journal of phycology 37 (6):975-986
Clifton KE (1997) Mass spawning by green algae on coral reefs. Science 275 (5303):1116
Cohen J (2008) Microbicide Fails to Protect Against HIV. Science 319 (5866):1026
Craigie JS (2010) Seaweed extract stimuli in plant science and agriculture. Journal of applied phycology:1-23. doi:10.1007/s10811-010-9560-4
Cruz-Suárez LE, León A, Peña-Rodríguez A, Rodríguez-Peña G, Moll B, Ricque-Marie D (2010) Shrimp/*Ulva* co-culture: A sustainable alternative to diminish the need for artificial feed and improve shrimp quality. Aquaculture 301 (1-4):64-68
Dai J, Zhang Q, Bao Z (1993) Genetic breeding and seedling raising experiments with Porphyra protoplasts. Aquaculture 111 (1-4):139-145
Dalton R (2002) Ocean tests raise doubts over use of algae as carbon sink. Nature 420 (6917):722-722
Dan A, Ohno M, Matsuoka M (1997) Cultivation of the green alga *Enteromorpha prolifera* using chopped tissue for artificial seeding. Suisanzoshoku (Japan)
Dawes CP (1995) Suspended cultivation of *Gracilaria* in the sea. Journal of applied phycology 7 (3):303-313
de Paula Silva PH, McBride S, de Nys R, Paul NA (2008) Integrating filamentous 'green tide' algae into tropical pond-based aquaculture. Aquaculture 284 (1-4):74-80
Doty M Status of marine agronomy, with special reference to the tropics. In, 1979. pp 35-58
Doty MS, Caddy J, Santelices B (1986) The production and use of *Eucheuma*. Case studies of seven commercial seaweed resources:123-164
Drew KM (1949) Conchocelis-phase in the life-history of *Porphyra umbilicalis* (L.) Kütz. Nature 164 (4174):748-749
Eklöf J, de La Torre Castro M, Adelsköld L, Jiddawi N, Kautsky N (2005) Differences in macrofaunal and seagrass assemblages in seagrass beds with and without seaweed farms. Estuarine, Coastal and Shelf Science 63 (3):385-396
Eklöf J, Henriksson R, Kautsky N (2006) Effects of tropical open-water seaweed farming on seagrass ecosystem structure and function. MEPS 325:73-84
FAO (2010) The state of world fisheries and aquaculture. FAO Fisheries and Aquaculture Department, United Nations, Rome

Fitton JH (2003) Brown marine algae: a survey of therapeutic potentials. Alternative & Complementary Therapies 9 (1):29-33

Fletcher RL (1995) Epiphytism and fouling in *Gracilaria* cultivation: an overview. Journal of applied phycology 7 (3):325-333

Funahashi H, Imai T, Tanaka Y, Tsukamura K, Hayakawa Y, Kikumori T, Mase T, Itoh T, Nishikawa M, Hayashi H (1999) Wakame Seaweed Suppresses the Proliferation of 7, 12 Dimethylbenz (a) anthracene induced Mammary Tumors in Rats. Cancer Science 90 (9):922-927

Ge L, Wang P, Mou H (2011) Study on saccharification techniques of seaweed wastes for the transformation of ethanol. Renewable Energy 36 (1):84-89

Glazer AN (1994) Phycobiliproteins—a family of valuable, widely used fluorophores. Journal of applied phycology 6 (2):105-112

Glenn EP, Doty MS (1990) Growth of the seaweeds Kappaphycus alvarezii, K. striatum and Eucheuma denticulatum as affected by environment in Hawaii. Aquaculture 84 (3-4):245-255

Goldstein Ph D (1970) Gametogenesis and fertilization in *Caulerpa*. Annals of the New York Academy of Sciences 175 (1):660-672

Hanaoka K, Yosida K, Tamano M, Kuroiwa T, Kaise T, Maeda S (2001) Arsenic in the prepared edible brown alga hijiki, *Hizikia fusiforme*. Applied organometallic chemistry 15 (6):561-565

Hayden HS, Waaland JR (2004) A molecular systematic study of *Ulva* (Ulvaceae, Ulvales) from the northeast Pacific. Phycologia 43 (4):364-382

Hehemann JH, Correc G, Barbeyron T, Helbert W, Czjzek M, Michel G (2010) Transfer of carbohydrate-active enzymes from marine bacteria to Japanese gut microbiota. Nature 464 (7290):908-912

Hernández-González MC, Buschmann AH, Cifuentes M, Correa JA, Westermeier R (2007) Vegetative propagation of the carrageenophytic red alga *Gigartina skottsbergii* Setchell et Gardner: Indoor and field experiments. Aquaculture 262 (1):120-128

Higashi T, Nagamori E, Sone T, Matsunaga S, Fukui K (2004) A novel transfection method for mammalian cells using calcium alginate microbeads. Journal of bioscience and bioengineering 97 (3):191-195

Hiraoka M, Oka N (2008) Tank cultivation of *Ulva prolifera* in deep seawater using a new “germling cluster” method. Journal of applied phycology 20 (1):97-102

Horstmann U (1983) Cultivation of the green alga, *Caulerpa racemosa*, in tropical waters and some aspects of its physiological ecology. Aquaculture 32 (3-4):361-371

Hurtado-Ponce A (1990) Vertical rope cultivation of *Gracilaria* (Rhodophyta) using vegetative fragments. Botanica Marina 33 (6):477-482

Hurtado-Ponce AQ, Agbayani RF, Chavoso EAJ (1996) Economics of cultivating *Kappaphycus alvarezii* using the fixed-bottom line and hanging-long line methods in Panagatan Cays, Caluya, Antique, Philippines. Journal of applied phycology 8 (2):105-109

Israel A, Levy I, Friedlander M Experimental tank cultivation of *Porphyra* in Israel. In: Eighteenth International Seaweed Symposium, 2007. Developments in Applied Phycology. Springer, pp 9-14. doi:10.1007/978-1-4020-5670-3_2

Jonasson A (1984) *Laminaria*-a modern cervix dilatation method with more than a 100-year history. Jordemodern 97 (6):187-195

Jousson O, Pawlowski J, Zaninetti L, Meinesz A, Boudouresque C (1998) Molecular evidence for the aquarium origin of the green alga *Caulerpa taxifolia* introduced to the Mediterranean Sea. Marine Ecology Progress Series 172 (0):275-280

Kalimuthu S, Kaliaperumal N, Ramalingam J (1991) Standing crop, algin and mannitol of some alginophytes of Mandapam coast. Journal of the Marine Biological Association of India 33 (1&2):170-174

Kawamoto H, Miki Y, Kimura T, Tanaka K, Nakagawa T, Kawamukai M, Matsuda H (2006) Effects of fucoidan from Mozuku on human stomach cell lines. Food science and technology research 12 (3):218-222

Kenicer G, Bridgewater S, Milliken W (2000) The ebb and flow of Scottish seaweed use. Botanical Journal of Scotland 52 (2):119-148

Kronick M, Grossman PD (1983) Immunoassay techniques with fluorescent phycobiliprotein conjugates. Clinical chemistry 29 (9):1582-1586

Kuwano K, Kono S, Jo YH, Shin JA, Saga N (2004) Cryopreservation Of The Gametophytic Cells Of Laminariales (Phaeophyta) In Liquid Nitrogen. Journal of phycology 40 (3):606-610

Kylin H (1956) Die Gattungen der Rhodophyceen. CWK. Gleerups, Lund

Lane CE, Mayes C, Druehl LD, Saunders GW (2006) A Multi Gene Molecular Investigation Of The Kelp (Laminariales, Phaeophyceae) Supports Substantial Taxonomic Re Organization. Journal of phycology 42 (2):493-512

Lewallen E, Lewallen J (1996) Sea vegetable gourmet cookbook and wildcrafter's guide, vol 1. Mendocino Sea Vegetable Company (Mendocino, Calif.),

Li D, Zhou Z, Liu H, Wu C (1999) A new method of *Laminaria japonica* strain selection and sporeling raising by the use of gametophyte clones. Hydrobiologia 398:473-476

Li X, Liu J, Cong Y, Qu S, Zhang Z, Dai H, Luo S, Han X, Huang S, Wang Q (2008) Breeding and trial cultivation of Dongfang No. 3, a hybrid of *Laminaria* gametophyte clones with a more than intraspecific but less than interspecific relationship. Aquaculture 280 (1-4):76-80

Liu F, Pang SJ, Chopin T, Xu N, Shan TF, Gao SQ, Sun S (2010) The dominant *Ulva* strain of the 2008 green algal bloom in the Yellow Sea was not detected in the coastal waters of Qingdao in the following winter. Journal of applied phycology 22 (5):1-10

Lüning K, Pang S (2003) Mass cultivation of seaweeds: current aspects and approaches. Journal of applied phycology 15 (2):115-119

Maeda H, Hosokawa M, Sashima T, Funayama K, Miyashita K (2005) Fucoxanthin from edible seaweed, *Undaria pinnatifida*, shows antiobesity effect through UCP1 expression in white adipose tissues. Biochem Biophys Res Commun 332 (2):392-397. doi:DOI:10.1016/j.bbrc.2005.05.002

Matsumura W, Yasui H, Yamamoto H (2001) Successful sporophyte regeneration from protoplasts of *Undaria pinnatifida* (Laminariales, Phaeophyceae). Phycologia 40 (1):10-20

McCarty M (1996) American macrobiotic cuisine. Penguin,

McHugh DJ (1987) Production and utilization of products from commercial seaweeds. FAO Fisheries Technical Paper (FAO). FAO, Rome (Italy),

Miyamura S (2005) Behavior of Flagella and Eyespot during Fertilization of Anisogametes in *Caulerpa racemosa* (Forsskål) J. Agardh var. *laetevirens* (Montagne)(Ulvophyceae, Chlorophyta) Revealed by Field Emission Scanning Electron Microscopy. Cytologia 70 (1):93-99

Morand P, Merceron M (2009) Macroalgal population and sustainability. Journal of coastal research 21 (5):1009-1020

Msuya FE, Neori A (2010) The Performance Of Spray Irrigated *Ulva Lactuca* (Ulvophyceae, Chlorophyta) As A Crop And As A Biofilter Of Fishpond Effluents. Journal of phycology 46 (4):813-817

Mulhall M (2008) Saving the Rainforest of the Sea: An Analysis of International Efforts to Conserve Coral Reefs. Duke Envtl L & Pol'y F 19:321

Naylor J (1976) Production, trade and utilization of seaweeds and seaweed products. In: FAO Fisheries Technical Paper: 159. Food and Agricultural Organization of the United Nations,

Neill K, Heesch S, Nelson W (2010) Diseases, pathogens and parasites of *Undaria pinnatifida*. Ministary of Agriculture and Foresty- Biosecurity, New Zealand, Wellington

Nelson W, Brodie J, Guiry M (1999) Terminology used to describe reproduction and life history stages in the genus *Porphyra* (Bangiales, Rhodophyta). Journal of applied phycology 11 (5):407-410

Neori A, Chopin T, Troell M, Buschmann AH, Kraemer GP, Halling C, Shpigel M, Yarish C (2004) Integrated aquaculture: rationale, evolution and state of the art emphasizing seaweed biofiltration in modern mariculture. Aquaculture 231 (1-4):361-391
Nisizawa K, Noda H, Kikuchi R, Watanabe T (1987) The main seaweed foods in Japan. Hydrobiologia 151 (1):5-29
Novaczek I, Athy A (2001) Sea vegetable recipes for the Pacific Islands. University of the South Pacific, Fiji
Ohba H, Nashima H, Enomoto S (1992) Culture studies on *Caulerpa* (caulerpales, chlorophyceae) III. Reproduction, development and morphological variation of laboratory-cultured *C. racemosa* var. *peltata*. Journal of Plant Research 105 (4):589-600
Ohno M, Largo DB, Ikumoto T (1994) Growth rate, carrageenan yield and gel properties of cultured kappa-carrageenan producing red alga Kappaphycus alvarezzi (Doty) Doty in the subtropical waters of Shikoku, Japan. Journal of applied phycology 6 (1):1-5
Ozaki A, Uchiyama M, Tagaya H, Ohida T, Ogihara R (2007) The Japanese Centenarian Study: autonomy was associated with health practices as well as physical status. J Am Geriatr Soc 55 (1):95-101. doi:10.1111/j.1532-5415.2006.01019.x
Pang SJ, Shan TF, Zhang ZH, Sun JZ (2008) Cultivation of the intertidal brown alga Hizikia fusiformis (Harvey) Okamura: mass production of zygote derived seedlings under commercial cultivation conditions, a case study experience. Aquaculture Research 39 (13):1408-1415
Pickering TD, Skelton P, Sulu RJ (2007) Intentional introductions of commercially harvested alien seaweeds. Botanica Marina 50 (5/6):338-350
Polne-Fuller M, Biniaminov M, Gibor A (1984) Vegetative propagation of Porphyra perforata. Hydrobiologia 116 (1):308-313
Polne-Fuller M, Gibor A (1986) Calluses, cells, and protoplasts in studies towards genetic improvement of seaweeds. Aquaculture 57 (1-4):117-123
Qi H, Rorrer GL (1995) Photolithotrophic cultivation of Laminaria saccharina gametophyte cells in a stirred tank bioreactor. Biotechnology and bioengineering 45 (3):251-260
Qin S, Jiang P, Yu D, Li F, Sun G (2010) Transformation of seaweed utilizing biolistic gene transfer to spores. US Patent, 7,663,026 B2, Feb 16, 2010,
Raymundo Piñero E, Cadek M, Wachtler M, Béguin F (2011) Carbon Nanotubes as Nanotexturing Agents for High Power Supercapacitors Based on Seaweed Carbons. ChemSusChem 4 (7):943–949. doi:DOI:10.1002/cssc.201000376
Reddy CRK, Jha B, Fujita Y, Ohno M (2008) Seaweed micropropagation techniques and their potentials: an overview. Journal of applied phycology 20 (5):609-617
Reith M, Munholland J (1993) A high-resolution gene map of the chloroplast genome of the red alga Porphyra purpurea. The Plant Cell Online 5 (4):465
Renn DW (1990) Seaweeds and biotechnology—inseparable companions. Hydrobiologia 204 (1):7-13
Roberts JN, Buck CB, Thompson CD, Kines R, Bernardo M, Choyke PL, Lowy DR, Schiller JT (2007) Genital transmission of HPV in a mouse model is potentiated by nonoxynol-9 and inhibited by carrageenan. Nature medicine 13 (7):857-861
Robertson-Andersson D, Leitao D, Bolton J, Anderson R, Njobeni A, Ruck K (2006) Can kelp extract (KELPAK®) be useful in seaweed mariculture? Journal of applied phycology 18 (3):315-321
Rosenberg JN, Oyler GA, Wilkinson L, Betenbaugh MJ (2008) A green light for engineered algae: redirecting metabolism to fuel a biotechnology revolution. Current opinion in biotechnology 19 (5):430-436
Santelices B (1999) A conceptual framework for marine agronomy*. Hydrobiologia 398:15-23
Sato M, Hosokawa T, Yamaguchi T, Nakano T, Muramoto K, Kahara T, Funayama K, Kobayashi A (2002) Angiotensin I-converting enzyme inhibitory peptides derived from wakame (Undaria pinnatifida)

and their antihypertensive effect in spontaneously hypertensive rats. Journal of agricultural and food chemistry 50 (21):6245-6252

Shimada S, Yokoyama N, Arai S, Hiraoka M Phylogeography of the genus *Ulva* (Ulvophyceae, Chlorophyta), with special reference to the Japanese freshwater and brackish taxa. In: Nineteenth International Seaweed Symposium, Kobe, 2009. Springer, pp 529-539

Smit AJ (2004) Medicinal and pharmaceutical uses of seaweed natural products: a review. Journal of applied phycology 16 (4):245-262

Smith S (1981) Marine macrophytes as a global carbon sink. Science 211 (4484):838

Stachowicz JJ, Graham M, Bracken MES, Szoboszlai AI (2008) Diversity enhances cover and stability of seaweed assemblages: the role of heterogeneity and time. Ecology 89 (11):3008-3019

Stiller JW, Waaland JR (1993) MOLECULAR ANALYSIS REVEALS CRYPTIC DIVERSITY IN PORPHYRA (RHODOPHYTA) 1. Journal of phycology 29 (4):506-517

Sudo Y, Araki A (2004) Research on the land culture of *Caulerpa lentillifera* using ocean deep water. Examination on the cultivation effect of ocean deep water. Okinawaken Kikaku Kaihatsubu Kaiyo Shinsosui Kenkyujo Kenkyu Gyomu Hokoku Heisei 14 Nendo Dai3go:76-81

Thornber CS, Kinlan BP, Graham MH, Stachowicz JJ (2004) Population ecology of the invasive kelp *Undaria pinnatifida* in California: environmental and biological controls on demography. Marine Ecology Progress Series 268:69-80

Troell M, Berg H (1997) Cage fish farming in the tropical Lake Kariba, Zimbabwe: impact and biogeochemical changes in sediment. Aquaculture Research 28 (7):527-544

Trono GC (1999) Diversity of the seaweed flora of the Philippines and its utilization. Hydrobiologia 398:1-6

Watanabe F, Takenaka S, Katsura H, Masumder SAMZH, Abe K, Tamura Y, Nakano Y (1999) Dried green and purple lavers (Nori) contain substantial amounts of biologically active vitamin B12 but less of dietary iodine relative to other edible seaweeds. Journal of agricultural and food chemistry 47 (6):2341-2343

Watt J, Marcus R (1971) Carrageenan-induced ulceration of the large intestine in the guinea pig. Gut 12 (2):164

Winterhalter P, Rouseff R Carotenoid-derived aroma compounds: an introduction. In: ACS Symposium Series, 2002. American Chemical Society, pp 1-19

Wright J (2005) Differences between native and invasive Caulerpa taxifolia: a link between asexual fragmentation and abundance in invasive populations. Marine Biology 147 (2):559-569

Xu Z, Dapeng L, Yiping Z, Xiaoyan Z, Zhaoling C, Wei C, Fan O (2002) Comparison of photobioreactors for cultivation of Undaria pinnatifida gametophytes. Biotechnology letters 24 (18):1499-1503

Yan L, Jianzhou C, Xueyan S, Tao L, Qingli G (2006) The Application of DNA Molecular Marker Technique in Heritable Breeding of Laminaria. Transactions of Oceanology and Limnology 1 (107):75

Yan X, Chuda Y, Suzuki M, Nagata T (1999) Fucoxanthin as the major antioxidant in Hijikia fusiformis, a common edible seaweed. Biosci Biotechnol Biochem 63 (3):605-607

Yokoyama H, Ishihi Y (2010) Bioindicator and biofilter function of *Ulva* spp.(Chlorophyta) for dissolved inorganic nitrogen discharged from a coastal fish farm-potential role in integrated multi-trophic aquaculture. Aquaculture 310 (1-2):74-83

Zemke-White W, Ohno M (1999) World seaweed utilisation: An end-of-century summary. Journal of Applied Phycology 11 (4):369-376

Zhang QS, Tang XX, Cong YZ, Qu SC, Luo SJ, Yang GP (2007) Breeding of an elite Laminaria variety 90-1 through inter-specific gametophyte crossing. Journal of applied phycology 19 (4):303-311

Zhang X, Xu D, Mao Y, Li Y, Xue S, Zou J, Lian W, Liang C, Zhuang Z, Wang Q (2011) Settlement of vegetative fragments of Ulva prolifera confirmed as an important seed source for succession of a large-scale green tide bloom. Limnology and oceanography 56 (1):233-242

Zhao FJ, McGrath SP, Meharg AA (2010) Arsenic as a food chain contaminant: mechanisms of plant uptake and metabolism and mitigation strategies. Annual Review of Plant Biology 61:535-559