Marine Plants & Algae

Organic Production and Handling

Identification of Petitioned Substance

Chemical Names:
Fertilizer: kelp meal, kelp powder, liquid kelp, microalgae; Phycocolloids: agar, agarose, alginate, carrageenans, fucoidan, laminarin, furcellaran, ulvan; Edible: *Ascophylum nodosum, Eisenia bicyclis, Fucus spp., Himanthalia elongata, Undaria pinnatifidia, Mastocarpus stellatus, Pelvetia canaliculata, Chlorella spp., Laminaria digitata, Saccharina japonica, Saccharina latissima, Alaria esculaenta, Palmaria palmata, Porphyra/Pyropia spp., Chondrus crispus, Gracilaria spp., Enteromorha spp., Sargassum spp., Caulerpa spp. Gracilaria spp., Cladosiphon okamuranus, Hypnea spp, Gelidiela acerosa, Ecklonia cava, Durvillaea antarctica and Ulva spp.*

Molecular Formula: Agar- $C_{14}H_{24}O_9$, Alginate- $C_6H_9O_7^-$, Carragenenans- iota- $C_{24}H_{34}O_{31}S_4^{-4}$, kappa- $C_{24}H_{36}O_{25}S_2^{-2}$,

Other Name: Kelp, Seaweed, Marine algae, Marine Aquatic Plant Extracts, polysaccharides from seaweed and microalgae; agar agar, Japanese gelatin, Japanese isinglass, vegetable gelatin, angel's hair; alginate, alginic acid, algin (sodium, potassium, ammonium, calcium, propylene glycol); carrageenans, iota carrageenans, kappa carrageenans

IUPAC Name: **Agar**- 2-(hydroxymethyl)-6-[(4-hydroxy-3-methyl-2,6-dioxabicyclo[3.2.1]octan-8-yl)oxy]-4-methoxyoxane-3,5-diol; **Alginate**- (3S,4S,5S,6R)-3,4,5,6-tetrahydroxyoxane-2-carboxylate; **iota-Carrageenans**- [(2R,3R,4R,5R,6S)-4,5-dihydroxy-6-[[(1R,3R,4R,5S,8S)-3-[(2R,3S,4R,5R,6S)-5-hydroxy-2-(hydroxymethyl)-6-[[(1R,3S,4R,5S,8S)-3-hydroxy-4-sulfonatooxy-2,6-dioxabicyclo[3.2.1]octan-8-yl]oxy]-3-sulfonatooxyoxan-4-yl]oxy-4-sulfonatooxy-2,6-dioxabicyclo[3.2.1]octan-8-yl]oxy]-2-(hydroxymethyl)oxan-3-yl] sulfate; **kappa-Carrageenans**- [(2R,3S,4R,5R,6S)-6-[[(1R,3S,4R,5R,8S)-3,4-dihydroxy-2,6-dioxabicyclo[3.2.1]octan-8-yl]oxy]-4-[[(1R,3R,4R,5R,8S)-8-[(2S,3R,4R,5R,6R)-3,4-dihydroxy-6-(hydroxymethyl)-5-sulfonatooxyoxan-2-yl]oxy-4-hydroxy-2,6-dioxabicyclo[3.2.1]octan-3-yl]oxy]-5-hydroxy-2-(hydroxymethyl)oxan-3-yl] sulfate;

Trade Names:
Arame, Badderlocks, Bladderwrack, Carola, Carrageen moss, Dulse, Gutweed, Hijiki (Hiziki), Irish moss, Laver, Kombu, Mozuku, Nori, Oarweed, Ogonori, Sea belt, Sea grapes (green caviar), Sea lettuce, Wakame, and Thongweed

CAS Numbers:
Agar: 9002-18-0; Alginate: 9005-32-7; iota-carrageenans-9062-07-1; kappa-carrageenans-11114-20-8;

Other Codes:
PubChem ID: Agar- 766450141; Alginate: 9166324; iota-carageenans-11966245, kappa-carrageenans- 11966249
InChl Key: Agar- GYYDPBCUIJTIBM-UHFFFAOYSA-N; Alginate- AEMOLEFTQBMNLQ-QTWKXLRFSA-M; iota-carrageenans- QIDSWKFAPCTSKL-RRQHLKGPSA-J; kappa-carrageenans- ZNOZWUKQPJXOIG-XSBHQQIPSA-L
Canonical Smiles: Agar- CC1C(C2C(C(O1)CO2)OC3C(C(C(C(O3)CO)O)OC)O)O; Alginate- C1(C(C(OC(C1O)O)C(=O)[O-])O)O; iota-carrageenans- C1C2C(C(O1)C(C(O2)O)OS(=O)(=O)[O-])OC3C(C(C(C(O3)CO)OS(=O)(=O)[O-])OC4C(C5C(C(O4)CO5)OC6C(C(C(C(O6)CO)OS(=O)(=O)[O-])O)O)OS(=O)(=O)[O-])O; kappa-carrageenans- C1C2C(C(O1)C(C(O2)O)O)OC3C(C(C(C(O3)CO)OS(=O)(=O)[O-])OC4C(C5C(C(O4)CO5)OC6C(C(C(C(O6)CO)OS(=O)(=O)[O-])O)O)O)O

Summary of Petitioned Use

Marine plants (seaweed) and algae are included in the National List in several sections and allowed for use in organic production and handling:

1) In §205.601(j)(1), Aquatic plant extracts are synthetic substances allowed in organic crop production, as plant or soil amendments, from other than hydrolyzed extracts where the extraction process is limited to the use of potassium hydroxide or sodium hydroxide; the solvent amount used is limited to that amount necessary for extraction.
2) In §205.605 (a) and (b), products from marine plants and algae including non-synthetic substances: alginic acid, agar and carrageenans, and the alginates are nonagricultural (nonorganic) substances allowed as ingredients in or on processed products labeled as ''organic'' or ''made with organic (specified ingredients or food group(s))'' and may be used as ingredients in or on processed products labeled as ''organic'' or ''made with organic (specified ingredients or food group(s))." In addition, some minerals used for nutrient fortification, such as calcium, may be derived from marine plants.
3) In §205.606 (d)(3), (n), (v) and (z), four substances from marine plants and algae are specifically identified as nonorganically produced agricultural products allowed as ingredients in or on processed products labeled as ''organic'' when the specific product is not commercially available in "organic" form: (d)(3) beta-carotene extract color, derived from algae (CAS #1393–63–1), not produced using synthetic solvents and carrier systems or any artificial preservative; (n) Kelp used only as a thickener and dietary supplement; (v) Pacific kombu; and (z) Wakame seaweed (*Undaria pinnatifida*).
4) In addition calcium used for fortification may be derived from marine plants

Petitions have been received for agar-agar (04/26/95), alginates (4/26/1995), alginic acid (4/26/1995), β-carotene (10/11/11), calcium from seaweed (3/2/2007), carrageenans (4/1995), color: beta carotene (from algae) (7/20/2009), kelp (4/1995), laminarin (5/30/13), seaweed extract (10/3/14), seaweed, pacific kombu (8/17/2007) and seaweed, wakame (1/12/2007). Previously prepared technical reports are available for agar-agar (USDA National Organic Program, 1995a, 2011a), alginic acid (USDA National Organic Program, 2015a), alginates (USDA National Organic Program, 1995b, 2015b), aquatic plant extracts (USDA National Organic Program, 1995c, 2006), β-Carotene (USDA National Organic Program, 2012), carrageenans (USDA National Organic Program, 1995d, 2011b, 2016), colors derived from agricultural products (USDA National Organic Program, 2015c), color: beta carotene (USDA National Organic Program, 2011c), kelp (USDA National Organic Program, 1995e) and laminarin (USDA National Organic Program, 2015d). Substances on the National List lacking a technical review are: seaweed extract (10/3/14), seaweed, Pacific Kombu (8/17/2007) and seaweed, Wakame (1/12/2007).

The National List includes some overlap in species in the various material listings. Public comment provided to the NOSB has described serious concerns for potential conservation issues for wild marine algae species and overharvesting of some species in some geographic areas. The public also requested clarification of the species used, the geographic areas of their origin, their cultivability or lack thereof, the effects of wild harvesting techniques, feasibility of harvesting by individual species selection as opposed to multi-species harvesting by littoral or marine zone, extraction methods and the potential for heavy metal sequestration in some wild species. The NOSB requested that all of these issues be addressed by an up-to-date technical report covering marine plants and algae on the National List. This is a specialized review and specific questions were provided by the NOSB. Only these questions are answered.

Characterization of Petitioned Substance

Composition of the Substance:

The total value of farmed aquatic algae in 2010 and 2008 was estimated at US$5.7 billion and US$4.4 billion, respectively (FAO, 2014, 2012). In 2012, the seaweed industry continued to produce a variety of products with an estimated total annual production value of US$5.5–6 billion (FAO, 2014). Food products from seaweed for human consumption contributed about US$5 billion. Substances extracted from seaweeds – hydrocolloids – accounted for a large part of the remaining billion dollars, with smaller, miscellaneous uses, such as fertilizers and animal feed additives, making up the rest. The industry uses 7.5–8 million metric tons of wet seaweed annually, which is harvested either from naturally growing (wild) seaweed or from cultivated (farmed) crops. Naturally growing seaweeds are often referred to as wild seaweeds, in contrast to seaweeds that are cultivated or farmed. Seaweed farming has expanded rapidly with demand outstripping the supply available from natural resources. Commercial harvesting occurs in about 35 countries, spread between the northern and southern hemispheres, in waters ranging from cold, through temperate, to tropical. A few species dominate algal culture, with 98.9 percent of world production in 2010 coming from Japanese kelp (*Saccharina/Laminaria japonica*—mainly in the coastal waters of China), *Eucheuma* seaweeds (a mixture of *Kappaphycus alvarezii*, formerly known as *Eucheuma cottonii*, and *Eucheuma spp*.), *Gracilaria spp*., nori/laver (*Porphyra spp*.), wakame (*Undaria pinnatifida*) and unidentified marine macroalgae species (3.1 million metric tons, mostly from China). The remainder consists of marine macroalgae species farmed in small quantities (such as *Fusiform sargassum* and *Caulerpa spp.)* and microalgae cultivated in freshwater (mostly *Spirulina spp*., plus a small fraction of *Haematococcus pluvialis*) (FAO, 2012).

Seaweeds are classified into three broad groups based on pigmentation: brown, red and green; respectively, *Phaeophyceae*, *Rhodophyceae* and *Chlorophyceae* (Gallardo, 2015). Brown seaweeds are usually large, ranging from the giant kelp that can be as long as 20 m, to thick, leather-like seaweeds from 2 to 4 m long, to smaller species 30–60 cm long. Red seaweeds are usually smaller, generally ranging from a few centimeters to about a meter in length. Red seaweeds are not always red in color; they are sometimes purple. Green seaweeds are small, with a similar size range to that of the red seaweeds. Seaweeds are also called macro-algae distinguishing them from micro-algae (*Cyanophyceae*), which are microscopic in size, often unicellular, and are best known by the blue–green algae that sometimes bloom and contaminate rivers and streams (FAO, 2004).

Despite concern for degradation of threatened marine environments and the sustainability of ocean resources, the vast and largely unexplored taxonomic genomic and chemical diversity and complexity of marine organisms including algae is considered an "untapped" resource of valuable products and is currently under investigation at many levels (Gaspar et al., 2015; Stengel and Connan, 2015). Research and development in marine plants and algae are focusing on a range of products including some permitted for use in organic agricultural production. Although these products are shared across many algal species, screening and development for commercial products in wild and cultured algal species has often been disconnected from environmental and physiological data and concerns associated with marine habitats and their inhabitants.

<u>Source or Origin of the Substance:</u>

"Algae" is the plural of a 16th century Latin word, alga for seaweed. It is thought to be etymologically derived from the Latin word *alliga* for binding or entwining. The term "Algae" does not have a precise taxonomic meaning. It is generally thought that about 1.6 billion years ago a coccoid cyanobacterium, the earliest photosynthetic organism, was eaten by heterotrophic eukaryote. Rather than being digested the cyanobacterium was retained. The incorporation of the cyanobacterium through evolution involved a large reduction in the size of its genome, transfer of many of its gene functions to and from the host nucleus and the loss of its cell wall giving rise to a primary alga, i.e., unicellular red or green algae. Subsequent endosymbiotic events are proposed to have occurred when another eukaryote ate a primary red or green alga giving rise to additional membrane layers and new plastid based organelles and structures. Land plants eventually evolved from green algae, while evolving red, green and brown alga continued their development of new plastids, functions and structures enabling aquatic life (Keeling, 2004; Coelho et al., 2010).

Algabase, a database of information including many types of algae, currently lists 144,393 species and infraspecific names for algae and marine plants (Guiry and Guiry, 2016). Systematically, and based on the DNA sequence of ribosomal RNA genes, there are two kingdoms: Prokaryota and Eukaryota, eleven phyla: *Cyanophyta*, *Glaucophyta*, *Rhodophyta*, *Cryptophyta*, *Dinophyta*, *Haptophyte*, *Ochrophyta*, *Euglenophyta*, *Chlorarachniophyta*, *Chlorophyta* and *Charophyta*; six subphyla and thirty-eight classes of marine algae.

A list of products from marine algae and originating species is provided in Table 1. Table 2 provides a list of common edible marine alga and their scientific names. The following substances and foods from marine algae have been examined by the National Organic Program: agar-agar, alginates, alginic acid, β-carotene, calcium from seaweed, carrageenans, color: beta carotene (from algae), kelp, laminarin, seaweed extract, pacific kombu and wakame.

Table 1 Examples of Algal Species Uses*

Compound/Extract	Algal Species	Source	Continent of Production	Applications
Seaweed manure and extract				
Seaweed manure and extract	*Ascophullum nodosum* *Ecklonia maxima* *Laminaria/Saccharina spp.* *Fucus* *Sargassum spp.* Maerl *(Phymatolithon calcareum+Lithothamnion coralliodes*	Wild stock	Europe, Asia, Africa, America	Fertilizer
Polysaccharides				
Carbohydrates	*Mastocarpus stellatus*	Wild stock	Europe	Cosmetics
Polysaccharides	*Porphyredium cruentum* *Rhodella spp.* Cyanobacteria	Culture	Europe	Cosmetics
Agar (hydrocolloid)	*Geldinium spp.* *Gracillaria spp.*	Wild stock, except *Gracillaria*, wild stock and culture	Europe, Asia, America, Africa	Biotechnology, bacteriological agar, human food, agar agar, health products, horticulture
Alginates (hydrocolloid)	*Ascophyllum nodosum* *Durvillaea potatorum* *Ecklonia maxima* *Laminaria/Saccharina spp.* *Lesonia nigrescens* *Macrocystis pyrifera*	Wild stock, except cultured *Laminaria/ Saccharina* spp.	Europe, Asia, Africa America	Pharmaceutical and Medical industry, cosmetics, human food, immobilized biocatalyst, paper industry, animal food
Carrageenan (hydrocolloid)	*Eucheuma denticulatum* *Kappaphycus alvarezii* *Gigarina skettsbergii* *Sarcothalia crispata* *Chondrus crispus*	Wild stock, except cultured *Euchema spp.* and *Kappaphycus spp.*	Asia, Africa, Europe, America	Human food, pharmaceutical and medical industries
Ulvans	*Ulva spp.*	Culture and wild stock	Europe	Animal feed
Fucanes (fucoidan)	*Ascophyllum nodosum*	Wild stock	Europe	Cosmetics, human food, nutraceuticals, animal feed, pharmaceutical
Laminarin	*Laminariales*			Horticulture
Fatty Acids				
Fatty Acids	*Chlorella spp.* *Syncchocystis spp.* *Chlamydomonas spp.* *Isochrysis spp.*	Culture	Europe, America, Asia-Pacific	Biofuel
Docosahexaenoic acid (DHA) Eicosapentaenoic acid (EPA)	*Crypthecodinium cohnii* *Schizoclrtrium sp.* *Nannochloropsis spp.* *Spirulina/Arthrospira spp.* *Ulkenia spp.*	Culture (heterotrophy mainly), Genetic engineering	Europe, America, Asia-Pacific (Australia)	Nutraceutical, pharmaceutical, animal feed
Pigments				
β-Carotene	*Dunaliella salina* *Hematococcus pluvialis*	Culture	Asia, Asia-Pacific, America	Animal feed, human food, pharmaceutical, nutraceutical
Astaxanthin	*Hematococcus pluvialis* *Chlorella spp.*	Culture	Asia, Asia-Pacific, America	Animal feed, nutraceutical, pharmaceutical
Canthaxanthin	*Hematococcus pluvialis* *Chlorella spp.* Green algae	Culture	Asia, Asia-Pacific, America	Animal feed

Table 1 Examples of Algal Species Uses (cont.)

Echineone	*Botryococcus braunii* *Cyanobacteria*	Culture		Animal feed
Fucoxanthin	*Phateodactylum tricornutum*	Culture		Nutraceutical, pharmaceutical
Lutein	*Scenedesmus spp.* *Muriellopsis spp.* Green algae	Culture		Nutraceutical, pharmaceutical
Zeaxanthin	Chlorella ellipsoidea Dunliella salina (mutant)	Culture		Animal feed
Phycobiliprotein	*Spirulina/Arthrospira spp.* *Pophryidium spp.* *Rhodella spp.* *Galdieria spp.* Cyanobacteria, Rhodophyta, Cryptophyta, Glaucophyta	Culture	Asia-Pacific, America	Human food, cosmetics, histochemistry, fluorescence microscopy, flow cytometry, nutraceutical, medical
Other compounds				
Mycosporine-like amino acids	*Porphyra umbicalis* Cyanobacteria	Culture		Cosmetics
Organohalogenated compounds	Asparagopsis armata	Culture	Europe	Cosmetics
Phloropanins (phenolics)	Fucales	Wild stock		Pharmaceutical
Phtotene, phytofluene	*Dunaliella spp.*	Culture		Cosmetics
Polyhdroxyalkanoates	Syncchocystis spp. Nostoc spp. Cyanobacteria	Culture		Bioplastics
Squalene	Auantiochrytrium spp.	Culture		Cosmetics
*Adapted from Stengel and Connan, 2015				

Table 2 Common Edible Seaweed*

Common Name	Scientific Name
Arame	*Eisenia bicyclis*
Badderlocks	*Alaria esculenta*
Bladderwrack	*Fucus vesiculosus*
Carola	*Callophylus variegata*
Carrageen Moss	*Mastocarpus stellatus*
Dulse	*Eucheuma cottoni*
Gutweed	*Enteromarpha intestinalis*
Hijiki (hiziki)	*Sargassum fusiforme*
Irish Moss	*Chondrus crispus*
Laver	*Porphyra lacinata/ Porphyra umbilicalis*
Limu kala	*Sargassum echinocarpum*
Kombu	*Laminaria spp.*
Mozuku	*Cladisiphon okamuranus*
Nori	*Porphyra spp.*
Oarweed	*Laminaria digitata*
Ogonori	*Gracileria*
Sea belt	*Laminaria saccharina*
Sea grapes (green caviar)	*Caulerpa lentillifera*
Sea lettuce	*Ulva spp.*
Thongweed	*Himanthalia elongata*
Wakame	*Undaria pinnatifida*
*Adapted from Venugopal, 2011	

Properties of the Substance:

Algae are unicellular or multicellular organisms. Algae that produce chlorophyll a and the accessory pigment β-carotene are called autotrophs. An autotroph is an organism that is able to synthesize its own food from simple inorganic substances such as carbon dioxide. With the exception of the cyanobacteria, algae have cellular organelles surrounded by membranes. In general, the cells of eukaryotic algae are surrounded by a cell wall which is produced by the Golgi apparatus. The cell wall is made up of cellulose and polysaccharides. As a result it has a fibrillar appearance. Algal cells have numerous organelles, among which the mitochondria, chloroplast and the nucleus are surrounded by a double membrane (Gallardo, 2015).

There is considerable variability in the taxonomic organization of algae, from unicellular organisms only a few microns in size to complex thalli (leaf-like structures), such as the large brown kelp, *Macrocystis* that can reach 300 feet in length. Algae show great diversity in their propagation mechanisms. In addition to sexual reproduction, simple multicellular thalli can vegetatively reproduce by fragmentation. While some species of brown algae, produce specialized structures of vegetative reproduction (Gallardo, 2015).

Sexual reproduction is known in most of the multicellular algal species. For many algae species, their reproductive cells are flagellate and motile. Sexual reproduction by means of these specialized cells can involve alternating nuclear phases and a zygote that never develops a multicellular embryo, e.g. a seed. Fertilization may occur via indistinguishable gametes, and though monoecious or dioecious production of male of female gametes. There are three basic life cycles in the sexual reproduction of algae—a) the haplontic reproductive cycle: meiosis takes place in the first division of the zygote, a single generation is called monogenetic; b) the diplontic and monogenetic reproductive cycle: meiosis occurs during gametogenesis, gametic meiosis, is as it is in animals and there are only diploid individuals; c) the haplodiplontic reproductive cycle: alternating generations, two different types of individuals alternate, one haploid gametophyte that produces gametes and the other diploid sporophyte that produces spores (Gallardo, 2015).

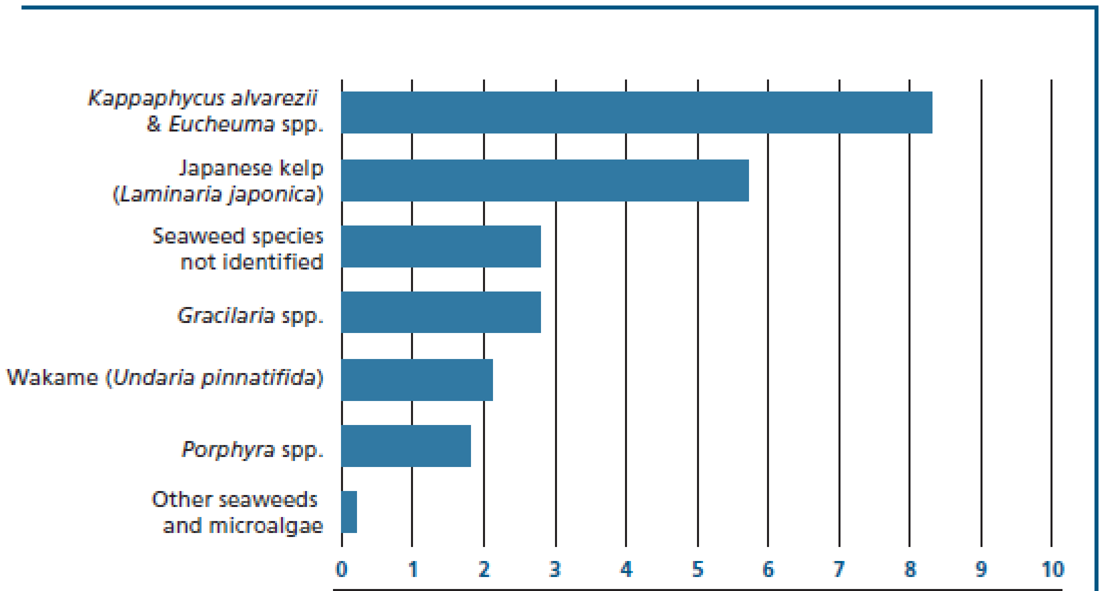
Marine algae produce, secrete and sense a wide variety of chemicals that control important functions such as reproduction, vegetative colonization, temperature acclimatization, disease resistance and herbivore defense. Chemicals include a wide array of organic chemical substances such as halogenated compounds, isoprenoids, monoterpenes, sequiterpenes, diterpenes, higher terpenes, steroids, acetogenins, oxylipins, polyketides, alkylated phenyl and quinone derivatives, phlorotannins, bromophenols, peptides, alkaloids and mycosporine-like amino acids (Young et al., 2015). These chemicals not only influence other algae of the same species and other species, e.g. determining a location where a plant can grow vegetatively, but also control the ecology of predators and symbionts. The chemical diversity of algae is linked to evolution, but phenotypic differences also result from environmental and biological pressures. Local conditions and sites where algae is collected or farmed, such as light, nutrient and temperature combinations have a significant impact on metabolic levels, responses and chemical composition. Biological status including life cycle, developmental stage, thallus structure and other factors also influence biochemical composition and the eventual value of the harvested material (Stengel and Connan, 2015).

Specific Uses of the Substance:

In 2012, about 23.8 million metric tons worldwide of seaweed and other algae were harvested from aquaculture. Capture production or wildcrafting produced about 1.1 million metric tons. Seaweed was used as food, in cosmetics and fertilizers, processed to extract thickening agents, and as an additive to animal feed (FAO, 2014).

The recorded use of seaweed as food dates to the fourth century in Japan and the sixth century in China. Increasing demand over the last fifty years outstripped the ability to supply the market from natural (wild) stocks. Cultivation industries now produce more than 90 percent of the markets' demand. In Ireland, Iceland and Nova Scotia (Canada), a different type of seaweed has traditionally been eaten, and this market is being developed. Some government and commercial organizations in France have been promoting seaweeds for restaurant and domestic use, with some success. An informal market exists among coastal dwellers in some developing countries where there has been a tradition of using fresh seaweeds as vegetables and in salads (FAO, 2012).

China has been the largest producer of edible seaweeds, harvesting about 5.5 million wet metric tons. The greater part of this is for Kombu, produced from hundreds of hectares of the brown seaweed, *Laminaria japonica* that is grown on suspended ropes in the ocean. The Republic of Korea grows about 800,000 wet metric tons of three different species, and about 50 percent of this is for Wakame, produced from a different brown seaweed, *Undaria pinnatifida*, grown in a similar fashion to *Laminaria* in China. Japanese production is around 600,000 wet metric tons and 75 percent of this is for nori, the thin dark seaweed wrapped around a rice ball in sushi. Nori is produced from a red seaweed, a species of *Porphyra*. It is a high value product, about US$ 16,000/dry metric ton, compared to Kombu at US$ 2,800/dry metric ton and wakame at US$ 6 900/dry metric ton. A comparison of the marine algae aquaculture species is provided in Fig 1.



Millions of metric tons (wet weight)

Fig. 1 World aquaculture production of farmed aquatic algae grouped by nature and intended use (FAO, 2014)

Various red and brown seaweeds are used to produce three hydrocolloids: agar, alginate and carrageenan. A hydrocolloid is a non-crystalline substance with very large polymeric molecules that dissolves in water producing a thickened (viscous) solution. Alginate, agar and carrageenan are used to thicken aqueous solutions, to form gels (jellies) of varying degrees of firmness, to form water soluble films, and to stabilize some products, such as ice cream, e.g. they inhibit the formation of large ice crystals so that the ice cream can retain a smooth texture (FAO, 2004).

Seaweeds as a source of hydrocolloids dates back to 1658, when the gelling properties of agar that is extracted with hot water from a red seaweed were first discovered in Japan. Extracts of Irish moss, another red seaweed, contain carrageenan and were popular as thickening agents in the nineteenth century. It was not until the 1930s that extracts of brown seaweeds, containing alginate, were produced commercially and sold as thickening and gelling agents. Industrial uses of seaweed extracts expanded rapidly after the Second World War, but were sometimes limited by the availability of raw materials. Once again, research into life cycles has led to the development of cultivation industries that now supply a high proportion of the raw material for some hydrocolloids. Alginate production (US$ 213 million) is from brown seaweeds, all of which are harvested from the wild; cultivation of brown seaweeds is too expensive to provide raw material for industrial uses (FAO, 2004).

Agar production (US$ 132 million) is principally from two types of red seaweed, one of which has been cultivated since the 1960–70s, but on a much larger scale since 1990, and this has allowed the expansion of the agar industry (FAO, 2004).

Carrageenan production (US$ 240 million) was originally dependent on wild seaweeds, especially Irish moss, a small seaweed growing in cold waters, with a limited resource base. However, since the early 1970s the industry has expanded rapidly because of the availability of other carrageenan-containing seaweeds that have been successfully cultivated in warm-water countries with low labor costs. Today, most of the seaweed used for carrageenan production comes from cultivation, although there is still some demand for Irish moss and some other wild species from South America (FAO, 2004).

Seaweed meal, used an additive to animal feed, has been produced in Norway, where its production was pioneered in the 1960s. It is made from brown seaweeds that are collected, dried and milled. Approximately 50,000 metric tons of wet seaweed are harvested annually to yield 10,000 metric tons of seaweed meal, which is sold for US$ 5 million. Fertilizer uses of seaweed date back at least to the nineteenth century. Early usage was by coastal dwellers, who collected storm-cast seaweed, usually large brown seaweeds, and dug it into local soils. The high fiber content of the seaweed acts as a soil conditioner and assists moisture retention, while the mineral content is a useful fertilizer and source of trace elements. In the early twentieth century, a small industry developed based on the drying and milling of mainly storm-cast material, but it dwindled with the advent of synthetic chemical fertilizers. Organic farming produces limited demand for fertilizer from harvested dried algae; however, the combined costs of drying and transportation have confined usage to sunnier climates where the buyers are not too distant from the coast. One growth area in seaweed fertilizers is in the production of liquid seaweed extracts that can be produced in concentrated form for dilution by the user. Seaweed fertilizers can be applied directly onto plants or watered in around the root areas. Organic farming provides a market for liquid seaweed fertilizers as a result of wider recognition of the usefulness of the products and their effectiveness in growing of vegetables and some fruits (FAO, 2004).

Cosmetic products, such as creams and lotions, sometimes show on their labels that the contents include "marine extract", "extract of alga", "seaweed extract" or similar. Usually this means that one of the hydrocolloids extracted from seaweed has been added. Alginate or carrageenan could improve the skin moisture retention properties of the product. Pastes of seaweed, made by cold grinding or freeze crushing, are used in thalassotherapy, where they are applied to the person's body and then warmed under infrared radiation. This treatment, in conjunction with seawater hydrotherapy, is said to provide relief for rheumatism and osteoporosis.

Approved Legal Uses of the Substance:

The U.S. Food and Drug Administration (FDA) has determined that agar is a generally recognized as safe (GRAS) direct food substance (21 CFR 184.1115). It is permitted in foods up to the maximum levels of 0.8% in baked goods, 2.0% in confections and frostings, 1.2% in soft candy, and 0.25% in all other food categories. It is also regarded by FDA as GRAS for use as a stabilizer in animal drugs, feeds, and related products when used in accordance with good manufacturing or feeding practices (21 CFR 582.7115). The FDA permits the use of agar in over-the-counter (OTC) drug products used as bulk laxative, however, the data are currently inadequate to establish GRAS and effectiveness of agar for this specific use—21 CFR 310.545 (NOP, 2011a).

Alginic acid is listed at 21 CFR 184.1011 as a GRAS direct food substance with specific limitations for use as an emulsifier, emulsifier salt, formulation aid, stabilizer and thickener in soups and soup mixes. Alginic acid is listed by the EPA as both an inert material approved for use in non-food use pesticides and as a former List 3 inert of unknown toxicity as included on the list of inert ingredients last updated in August of 2004 (NOP, 2015a). Alginates are GRAS in food when produced according to good manufacturing processes. The FDA provides specific uses and levels of concentration allowed for the different alginate salts (ammonium, calcium, potassium and sodium) (21 CFR 294— 184.1133, 184.1610, 184.1724, 184.1187). In addition, sodium and propylene glycol alginate are permitted as ingredients in standardized pasteurized Neufchatel and processed cheese spreads (21 CFR 133.178 and 133.179). Polypropylene glycol alginate is also allowed as a coating for fresh citrus fruit per 21 CFR 172.210, as a defoaming agent in processed foods per 21 CFR 173.240, and as an indirect food additive (components of paper and paperboard) per 21 CFR 176.170 (NOP, 2015b).

Aquatic plant extracts of *Ascophyllum nodosum* (CAS number 84775-78-0) are on EPA's former List 4B of inert ingredients in pesticides. EPA exempts cytokinin in aqueous extract of seaweed meal (as opposed to seaweed extract) from the requirement for a tolerance in all food commodities when used as a plant growth regulator on plants, seeds, or cuttings and on all food commodities after harvest (NOP, 2006). Laminarin is exempt from tolerance in or on all food commodities when it is applied pre-harvest as a biochemical pesticide to stimulate natural defense mechanisms in plants—40 CFR 180.1295 (NOP, 2015d). Kombu (Laminaria japonica) and its extract are generally recognized as safe by the FDA (GRN. 000123—21 CFR 184.1120). The FDA considers fucoidan from *Undaria pinnatifida* generally regarded as safe for use in baked goods (e.g., bread, cake), noodles, soups, snack foods, imitation dairy products, and seasonings and flavors at use levels up to 30 milligrams per serving. The edible seaweed wakame is also produced by drying *Undaria pinnatifida* and is generally regarded as safe (FDA GRN No. 565 — 21 CFR 184.1120).

β-carotene from seaweed is listed as GRAS by the FDA in 21 CFR 184 and exempt from certification in 21 CFR 73.95 (NOP, 2012).

Carrageenan may be safely used as a direct food additive for human consumption as follows: a) it is prepared by aqueous extraction only from eight species of Rodophyceae (red) seaweeds: *Chondrus crispus*, *Chondrus ocellatus*, *Kappaphycus alvarezeii* (*Eucheuma cottonii)*, *Eucheuma spinosum*, *Gigartina acicularis*, *Gigartina pistillata*, *Gigartina radula*, and *Gigartina stellate*; b) it is a sulfated polysaccharide composed primarily of glactose and an hydrogalactose with a sulfate content of 20-40% dry weight; c) it is used only in the amount necessary as an emulsifier, stabilizer, or thickener in foods, except for those standardized foods that do not provide for such use and d) foods with carrageenan added must be labeled "carrageenan"—21 CFR 172.620. Salts of carrageenan are also permitted for safe use as a direct food additive under 21 CFR § 172.626 (NOP, 2011b).

Action of the Substance:

Marine plants and algae include a wide variety of organisms that range in complexity from a picoplanktonic cells to macroalgal kelp (Stengel and Connan, 2015). There are about 20,000 defined species worldwide belonging to one of three groups: green algae, brown algae and red algae. A number of algae or seaweed species have played an important role in commerce and providing food and food products for centuries. These plants possess chlorophyll, but lacking true roots, stems and leaves are distinct from terrestrial green plants comprising commodities grown in organic or conventional agricultural production. Unlike an organic agriculture production system where provisions are made to foster soil fertility by managing the organic content of the soil with proper tillage, crop rotation and manuring, there is no soil to manage and organic aquaculture does not require manure, tillage or crop rotation. Furthermore, the animal population within the marine environment, consists mostly of fish and invertebrates that do not produce manure containing urea. Instead they produce feces containing ammonia that rapidly dissolves in the surrounding water. Without roots, seaweed may be free floating or attach preferably to a hard surface and the entire crop self regulates growth based on prevailing water conditions and temperature. Because soil and humus are not part of the growth medium and not factors in aquaculture generally accepted practices for sustainability, productivity and profitability affecting terrestrial crop production are not applicable in organic aquaculture.

Much of early algae production required the harvest of wild crops. *Ascophyllum nodusum*, "rockweed" is a brown algae species that has not been cultivated, but has value as a raw material for fertilizer, animal feed and alginate. It has been harvested commercially since 1959. Overharvesting of this cold water species has led to regulatory limitation of the harvest to 17%of harvestable biomass, although practically this ranges from 15 to 50%. Harvesting methods also evolved from automated suction cutters to simple manual cutter rakes (Ugarte et al., 2006, 2012). Although much of the cut rockweed grows back before it may be subjected to reharvest, taking about six years, the effect of the harvest on plant and animal species living in and on the rockweed forest is still under study. One study addressing the major components of the resident fish community in the rocky intertidal zone after rockweed harvest found no evidence linking rockweed harvest to changes in the ichthyoplankton component or the juvenile and adult fish of that community (van Guelpen and Pohle, 2014). In a summarized review of selected work, a researcher at the University of Maine also concluded that the effect of 17% rockweed harvest on some species including seabirds was negligible (Beal, 2015). In Canada, and the north Atlantic United States, both governments and commercial producers have endeavored to manage resources of *Ascophyllum nodosum* to 1) maintain its economic value and 2) ensure that their efforts do not interfere with other resources such as marine fisheries (Ugarte and Sharp, 2012).

It is common in this century that natural resources are increasingly under pressure to provide food and resources for a growing world population (Ginneken and de Vries, 2016). It is apparent that this is the case with "rockweed," one of eight brown seaweed species harvested internationally to manufacture alginate, where increasing capital investment for social responsibility and sustainability is required. Alginates now provide the basis for many technologies in foods, pharmaceuticals, and medical products and research in these areas continues. *Laminaria hyperborea* (Northern Europe), *Laminaria digitata* (Mediterranean Atlantic), *Laminaria japonica* (Japan, China, Korea), *Ascophyllum nodosum* (Northeastern US and Canada), *Ecklonia spp.* (South Africa, Southern Australia, New Zealand), *Lessonia spp.* (Peru, Chile), *Macrocystis pyrifera* (California) and *Durvillaea spp*. (Southern Australia) are the eight primary species wild harvested for alginate production. Because the structure and application of the alginates of brown algae vary depending upon the species and the water temperature where they grow, quotas of varying amounts of wet product are determined based on demand for specific products. Companies and organizations involved in the harvest of brown algae used for alginate production work with international regulators and environmental advocates to harvest responsibly to sustain regrowth, preserve their resource and provide economic development for the communities involved in wild crafting and harvest (FMC, 2003; Canadian Science Advisory Secretariat, 2013; Maine Seaweed Council, 2014).

The efficiency of the photosynthetic process of a terrestrial crop or seaweed from the oceans is ultimately a reflection of the growth that ultimately determines the amount of green biomass harvested. Seaweeds "the unforeseen crop of the future" and other marine plants are the primary producers in the marine environment. They form the standing crop and determine the productivity of all communities. Seaweed-based ecosystems are amongst the most productive on Earth (van Ginnekin and De Vries, 2016). Notwithstanding, rockweed has an important role as habitat, as food and as a nutrient source supporting a community of organisms that inhabit its "forests." Any cutting of rockweed can produce an effect on the supported eco-communities. Furthermore, many aspects of this ecosystem have not been elucidated, encouraging more precaution as the brown algae "forestry" industry grows into the future (Seeley and Schlesinger, 2012).

Combinations of the Substance:

Marine plants and algae are used to produce agar, carrageenan, alginates, and β-carotene as a colorant. These functional ingredients are used in combination with many foods, food additives, functional products and health products. Seaweeds used for fertilizers (soil amendments), i.e. aquatic plant extracts, are often extracted with alkali, e.g. potassium hydroxide or sodium hydroxide (§205.601).

Status

Historic Use:

Marine Plants and Algae or seaweeds have been used by people for many centuries as food and as a source for chemicals. At an archeological site in southern Chile, remains of nine species of marine algae were recovered from hearths and other features at Monte Verde II, an upper occupational layer, and were directly dated between 14,220 and 13,980 calendar years before the present (~12,310 and 12,290 carbon-14 years ago). These findings support the archaeological interpretation of the site and indicate that the site's inhabitants used seaweed from distant beaches and estuarine environments for food and medicine (Dillehay et al., 2008). In China, archaeological evidence from as long ago as 3000 BCE describe the use of seaweed for food. In the twelfth century, seaweed was used in Europe for fertilizer and animal feed. During the 18th century burning kelp became a source for sodium carbonate (ash). Carrageenan from Irish moss followed in the 19th century. Optimism prevailed at this time about an unlimited source of seaweed and other products such as agar and alginate followed. In addition as the world has internationalized, seaweed consumption as food, e.g. Kombu, Nori and Wakame, has expanded from China, Japan and Korea to the entire world. Farming seaweed on lines in the ocean has expanded globally for production of alginates, carrageenans, other chemicals and the edible seaweed varieties, as management of harvest of wild seaweed forests continues throughout the world (Hunter, 1975).

Organic Foods Production Act, USDA Final Rule:

Aquatic plants and their products may be certified under current USDA organic regulations. Producers and certifiers are required to comply with USDA organic regulations when producing or certifying cultured and wild crop harvested plants. Aquatic plant producers must ensure and certifying agents must verify that production practices maintain or improve the natural resources of the operation including water quality (McEvoy, 2012).

Marine plants (seaweed) and algae are included in the National List in several sections and allowed for use in organic production and handling:

1) In §205.601(j)(1), Aquatic plant extracts are synthetic substances allowed in organic crop production, as plant or soil amendments, from other than hydrolyzed extracts where the extraction process is limited to the use of potassium hydroxide or sodium hydroxide; the solvent amount used is limited to that amount necessary for extraction and the use of aquatic plant extracts does not contribute to contamination of crops, soil, or water.

2) In §205.605 (a) and (b), products from marine plants and algae including non-synthetic substances: alginic acids, agar and carrageenans, and the synthetic substances: alginates are nonagricultural (nonorganic) substances allowed as ingredients in or on processed products labeled as ''organic'' or ''made with organic (specified ingredients or food group(s))'' and may be used as ingredients in or on processed products labeled as ''organic'' or ''made with organic (specified ingredients or food group(s))." In addition, some minerals used for nutrient fortification, such as calcium, may be derived from marine plants.

3) In §205.606 (d)(3), (n), (v) and (z), four substances from marine plants and algae are specifically identified as nonorganically produced agricultural products allowed as ingredients in or on processed products labeled as ''organic'' when the specific product is not commercially available in "organic" form: (d)(3) beta-carotene extract color, derived from algae (CAS #1393–63–1), not produced using synthetic solvents and carrier systems or any artificial preservative, (n) Kelp used only as a thickener and dietary supplement, (v) Pacific kombu and (z) Wakame seaweed (*Undaria pinnatifida).*

International

Canada - Canadian General Standards Board Permitted Substances List. This list was updated in November 2015.

Although there is a Canadian organic aquaculture standard and accredited certifying bodies can certify to it, the standard itself is not referenced in government regulations and organic aquaculture products may not carry the Canada Organic logo. Aquatic plants and aquatic plant products not containing synthetic preservatives, such as formaldehyde, either extracted naturally (non-synthetic) or with potassium hydroxide or sodium hydroxide in approved situations are allowed as soil nutrients and amendments. Agar is also permitted a medium for spawn production.

CODEX Alimentarius Commission, Guidelines for the Production, Processing, Labelling and Marketing of Organically Produced Foods (GL 32-1999) -

A proposal to amend the Codex guidelines to include organic aquaculture, including algae and products of algae, has been under consideration. Due to consensus issues, it is unclear whether this proposal will be adopted in the future (CAC, 2016). The Codex guidelines for organic also allow: 1) seaweed and seaweed products as a soil conditioner, 2) seaweed, seaweed meal, seaweed extracts, sea salts and salty water for pest control, 3) Carrageenan, 4) Alginic acid/sodium alginate/potassium alginate and 5) agar.

European Economic Community (EEC) Council Regulation, EC No. 834/2007 and 889/2008

Aquaculture is defined by the EEC as the rearing or cultivation of aquatic organisms including marine plants and algae using techniques designed to increase the production of the organisms in question beyond the natural capacity of the environment; the organisms remain the property of a natural or legal person throughout the rearing or culture stage, up to and including harvesting.

Algae, including seaweed, can be used in the processing of organic food. Aquaculture production must be based on the maintenance of the biodiversity of natural aquatic ecosystems, the continuing health of the aquatic environment and the quality of surrounding aquatic and terrestrial ecosystems.

Japan Agricultural Standard (JAS) for Organic Production— The Japanese Agricultural Standard for Organic Plants (Notification 1065 of the Ministry of Agriculture, Forestry and Fisheries of October 27, 2005) allows the use of dried algae as fertilizer for terrestrial plants.

International Federation of Organic Agriculture Movements (IFOAM) –

IFOAM is developing a standard for marine algae in its aquaculture expert forum. Seaweed is allowed as a soil input in appendix 2 of the IFOAM norms (IFOAM, 2014). In addition, several hydrocolloids derived from algae such as carrageenan and alginates are allowed as additives (IFOAM, 2014).

NOSB Questions for Marine Plants and Algae

NOSB Question #1. Nomenclature: The brief information on each material provided here indicates that many of the National List listings are generic terms or overlapping terms, lacking specificity, such as "agar agar", "carrageenan", "aquatic plant extracts" or "kelp". Should each listing include specific Latin names of approved algae? Should the word "plant" be replaced by the word "algae?"

The term "algae" refers to a complex association of photosynthetic organisms, the taxonomy of which is indeterminate and being reexamined based on data from modern molecular genetics. Taxonomically algae can be divided into two groups. The multicellular marine algae (macroalgae, seaweed) and unicellular algae, which inhabit both the ocean and freshwater lakes, pond, soils, etc. Algae are not lower plants when compared to terrestrial plants growing in the soil. They have evolved independently and are "state of the art" for their habitats. The terms "algae" and "seaweed" are used interchangeably in the literature. The term "marine plant" is not generally used to describe the algae, rather it describes rhizomatous angiosperms such as the seagrasses that thrive in a soft substrate. Seagrasses are phylogenetically more closely related to mangroves and terrestrial plants than to the red, green or brown macro algae species. They are likely to have adapted to marine environment from a terrestrial environment. However, because algae are plants that live in the ocean they are often referred to as marine plants in the technical literature.

The chemical composition of algal biomass depends on its taxonomy. The main components are often polysaccharides that have structural or storage functions. Table 3 provides some of the seaweeds used to produce the industrial polysaccharides. Structural polysaccharides have unique properties that makes them valuable. For example the gelling algal polysaccharides, agars, carrageenans and alginic acids have a wide range of applications in the health, food and cosmetic industries and are produced on a large scale (Usov and Zelinsky, 2013).

The main polysaccharides of red algae are the sulfated galactans. These usually have a linear backbone built up of alternating 3-linked β-D-galactopyranose and 4-linked-α-galactopyranose residues. The configuration of the 4-linked-α-galactopyranose determines whether the sulfated galactan is agar or carrageenan. Dextrorotary or D for carrageenan and levorotary or L for agar. Some of the 4-residues may also be present as 3,6-anhydro derivatives. This allows for four types of repeating dissacharide units in the sulfated galactans and there are further modifications that can take place such as methylation, sulfation or substitution by a single saccharide residue. In addition to the sulfated galactans, Floridean starch, cellulose, mannans, xylans and sulfated mannans are also produced from the red algae.

Table 3 Some Seaweed as Sources of Marine Polysaccharides*

Polysaccharide	**Seaweed**
Agar, Agarose	*Gracillaria, Gelidium, Pterocladia*
Alginic Acid (Alginate)	*Macrocystis, Laminaria, Ascophyllum, Sargassum*
Carrageenans	*Gigartina, Chondrus, Kappaphycus (Euchema)*
Fucoidan	*Fucus serratus*
Laminarin	*Laminaria japonica* (brown seaweeds)
Furcelleran	*Furcellaria lumbricialis, F. fastigiata*
Ulvan	*Ulva rigida, Enteromporpha compressa*

*Adapted from Venugopal, 2011

The nomenclature of red algal polysaccharides is arbitrary. For example, agar and carrageenan are names given to polysaccharides from various alga before elucidation of their chemical structure, thus these particular substances are subject to wide chemical variation. The first two carrageenan fractions that were isolated were named kappa and lambda, after that the carrageenans were named by Greek letters without any system (Usov and Zelinsky, 2013). The principle species used for the commercial production of carrageenans are *Kappaphycus alvarezii* (*Euchemia cottonii), Euchema spinosum, Chondrus crispus*, *Furcellaria* spp and *Gigartina stellata* (Venugopal, 2011).

Polysaccharides from the brown algae include laminarans, alginic acids and fucoidans. Of these alginic acids are the most produced. The alginic acids are linear copolymers of two (1—>4)-linked uronic acid residues, β-D-mannuronic and α-L-guluronic acids. In the form of mixed salts (alginates) with several cations , i.e. Na^+, K^+, Mg^{2+} and Ca^{2+} they are present in the cell walls and intracellular matrices of all known brown algae (USov and Zelinsky, 2013). The alginates are produced in large scale mainly from *Laminaria saccharina*, *L. digitata*, *L. japonica*, *Ascophyllum nodosum* and *Macrocystis pyrifera*, but other species are also used: *Eckloina maxima, Eckloina cava, Eisenia bicyclis, Lessonia nigrecans* and *Sargassum spp* (Venugopal, 2011). These species are widely distributed occurring throughout the world mostly in temperate to relatively cold water.

β-carotene is a food coloring and nutritional supplement. It is a carotenoid and is found in all photosynthetic plants. In seaweed, β-carotene is part of the photosynthetic apparatus where it is inserted into the pigment protein antenna complexes acting as structural stabilizers for protein assembly in the photosystems and as inhibitors of either photo- or free radical oxidation provoked by excess light exposure. Macroalgae sources for β-carotene production are *Laminaria digitatus, Fucus serratus, F. vesiculosus, Ascophyllum nodosum, Sargassum spp., Ulva spp., Chondrus crispus, Porphyra spp.,* and *Palmaria palmatus* (Venugopal, 2011). Commercially most naturally produced β-carotene comes from the microalgae *Dunaliela salina* cultivated aquatically in saline ponds or tanks. *Dunaliella salina* is a unicellular green alga belonging to the *Chlorophyceae* family. It is known to accumulate carotenoids under various conditions of stress, such as high salinity, high light intensity, and low growth temperature. *Dunaliella salina* can tolerate a variety of environmental stresses, and is able to accumulate a beta-carotene percentage of up to 10% of its dry weight (Wu et al., 2016).

Whole algae incorporated into food and food additives has been used to develop healthier and more nutritious foods particularly because there is a technical advantage in the use of algae as natural ingredients in food reformulation for healthy foods and beverages. Wakame (*Undaria pinnatifida*) a widely consumed brown algae contains high levels of dietary fiber and minerals. It is used in meats to produce low fat and low salt products, improving water holding capacity and texture of processed products. Kombu (*Laminaria spp*.) or sea tangle containing alginic acids, fucoidan and laminaran has also been used in meat processing to improve water holding capacity and texture, as well as in dairy products, pasta, bread and many traditional Asian foods (Cofrades and Jimenez, 2013). Red algae (Macrocystis pyrifera) a source for alginate is also chopped and used as a source of Iodine added to food.

Aquatic Plant Extracts incorporating *Ascophyllum nodosum*, *Sargassum* spp., and *Laminaria* spp. are used as fertilizers for organic and non-polluting terrestrial farming. Seaweed extracts are rich in λ-carrageenans and can elicit an array of plant defense responses (Venugopal, 2011).

NOSB Question #2. Overharvesting: The nine listings include thousands of species of algae from many different geographic locations, marine intertidal zone, deeper ocean areas, and wild harvested beds. Which species, genera, Classes are being overharvested? Which geographic regions indicate overharvesting impact? What is the trend in harvesting marine algae? What is the present status and trends in harvesting and overharvesting of Ascophyllum nodosum?

There is one species of red algae and two species of brown algae growing along the coasts of the United States that have gained attention as ecologically threatened in recent years. They are respectively, Irish moss (*Chondrus crispus*), rockweed (*Ascophyllum nodosum*) and giant kelp (*Macrocystis pyrifera*). These plants are economically important and drive several seaweed industries including cosmetic products, nutraceuticals, fertilizers and hydrocolloids. Fertilizer applications are similar to farmyard manure, but may also include extracts and foliar applications (Chojnacka, 2012).

Kelp and rockweed, are foundational species forming large expansive marine habitats supporting a diverse range of wildlife, including other algal species, marine animals and many species of protozoans and bacteria (Seeley and Schlesinger, 2012). Without a good accounting of all of the species present it is hard to predict the effects of harvesting rockweed and kelp on each ecological niche. Thus, it has been important to recognize that sustainable seaweed production perceived as reproducible harvest capacity, may not guarantee the sustained subsistence of each resident species. Although not part of any agricultural waste stream, extracts from wild-harvested kelp and rockweed are allowed for use in organic production as soil amendments (§205.601(j)(1)).

To address potential overharvesting, the three marine algae species Irish moss (*Chondrus crispus*), rockweed (*Ascophyllum nodosum*) and giant kelp (*Macrocystis pyrifera*) are now harvested primarily using a hand rake, rather than powered devises and significant restrictions have been imposed by coastal regulators in North America that limit the harvest to approximately one fifth of the available biomass. Observations by researchers on regions following this ordinance have been favorable and positively supported by the

Table 4 Example of Regulatory Guidance for Sustainable Seaweed Production*

Maine Seaweed Council
2014 Harvest Guidelines for Maine Seaweeds

Common Name *Scientific Name*	Traditional Harvest Season	Traditional Harvest Height	% of biomass removal based on assessment at the beginning of the harvest	Method of Harvest
Dulse *Palmaria palmata*	5/1-10/31	Should be harvested above the holdfast	75% per harvest as regrowth permits	Although it is recognized that improper hand harvesting can lead to over harvesting, mechanical harvesting has the potential for removal of far more biomass in less time. For this reason, selectivity should be employed regardless of method of harvest and any form of harvesting should undergo careful scrutiny to verify that it is an environ-mentally concerned, ecological and sustainable method.
Bladderwrack, Fucus *F. vesiculosus, F. evanescens* [syn *Fucus edentatus*]	Year round	Should be harvested above the holdfast	30% per year	
Irish Moss (& false) *Chondrus crispus, Mastocarpus stellatus*	6/1-11/30	Should be harvested above the holdfast	30% per year	
Kelp, Fingered *Laminaria digitata* [syn *Saccharina digitata*]	Year round	Should be harvested above the holdfast	30% per year	
Kelp, Oarweed *Saccharina longicruris* [syn *Laminaria longicruris*]	3/1-8/31	Should be harvested above the holdfast	30% per year	
Kelp, Sugarwrack *Saccharina latissima* [syn *Laminaria saccharina*]	3/1-8/31	Should be harvested above the holdfast	30% per year	
Kelp, Winged *Alaria esculenta*	3/1-8/31	Should be harvested above the holdfast and sporophylls (wings)	30% per year	
Nori *Porphyra spp.*	4/1-10/31	Should be harvested above the holdfast	75% per harvest as regrowth permits	
Rockweed, Knottedwrack *Ascophyllum nodosum*	Year round	***SEE BELOW**	17% per year or 50% per 3 years	
Sea Lettuce *Ulva lactuca*	4/1-10/30	Should be harvested above the holdfast	75% per harvest as regrowth permits	
Wormweed *Ascophyllum nodosum f. scorpioides*	Year round	May be harvested in its entirety	75% per harvest as regrowth permits	
*** As defined by the Maine Dept. of Marine Resources Regulation 29.05:**	(1) "The lowest lateral branches shall remain undisturbed and attached to the main stalk of the rockweed that is attached to the substrate; and (2) a minimum of 16 inches of the rockweed shall remain above the holdfast"			

UPDATE: In 2013, the Department of Marine Resources began the challenging task of developing a framework of recommendations for the long-term management of the rockweed fishery (*Ascophyllum nodosum*). The Planning Development Team included a number of members of the Maine Seaweed Council. As new regulations are developed and approved, these Harvest Guidelines will incorporate the changes.

from Maine Seaweed Council, 2014.

resident seaweed harvesters and the associated industries. Table 4 provides information on Maine's seaweed harvest limits. Fines of up to $500.00 may be imposed for violations. Tile 12 Conservation, chapter 623, subchapter 4, §6803-6803C of the statutes of the state of Maine mandates requirements for permits, buying regulations and limits for harvesting of seaweed along its coast. These permits do not apply to seaweed that is detached naturally or dead. In 2014, the Maine legislature enacted H.P. 1318, an act to promote rockweed habitat conservation through the consideration of no-harvest areas, permitting the commissioner of marine resources to regulate seaweed harvest including closing designated areas.

The people of China and Japan have included the edible seaweeds in their diets for many centuries. Japanese national and local seaweed shellfish fisheries cooperative associations promote and develop seaweed aquaculture management to improve the economic stability of seaweed producers, promote widespread consumption of seaweed and support the fisheries economy. Historically, these cooperatives share maritime resources. However, not only the institutions are important. The physical arrangements for fisher-folk and the ecology of the seaweed are also important considerations in the success of sustainable seaweed harvesting in Japan. Kombu is a wild resource, the harvest of which dates back to the 18th century in Japan. Kombu harvesting in Japan can serve as an example of a "common rights fishery." In the early 1800s reports of villagers harvesting "as much Kombu as possible" and "paying little attention to its quality" began appearing. In response the Union for Improvement of Kombu for export was established in the Hidaka district of Kyoto. Kombu inspectors or "hatamochi" were elected from every village in the district for Kombu improvement. Their duties included preventing the harvest of Kombu on shady or rainy days when good quality Kombu could not be produced (Iida, 1998). This practice is now widespread in Japan but has been supplemented by the inclusion of licensing, assigned fishing zones, penalties for regulatory violations, permitted boat sizes, permitted harvesting tools, harvesting periods, and no harvest holiday observance. Because Kombu does not regenerate in the year following its harvest, the amount of Kombu for harvest decreases over the year. Yield is also influenced by the tide level, wave height, number of harvesters in each family, transport from the harvest to the shore and to drying areas, the knowledge and physical strength of the harvesters. In some isolated cases, the hatomochi will allow the families of sick Kombu harvesters to harvest on foot in shallow intertidal zones, in order to help in the care of the disabled fisherman. Otherwise this practice would be forbidden. Kombu harvesting regulations voluntarily observed by the fisher-folk and their enforcement by the "hatamochi" prevents intensive harvesting, resource depletion and the decline of Kombu quality. The rules support resource sustainability and the economic protection of the fisher-folk and their villages, ensuring equal access and supporting reserved competition without being ideally traditional or capitalistic (Iida, 1998).

Macroalgae habitats are parametrically defined by a range of environmental variables including temperature, depth of water, salinity, substrate type and turbidity. If resident conditions aren't within the range of survivability for a particular species then its range changes and the species declines in that particular area. Modeling studies on the brown algae, (*Laminaria digitata*), kelp have shown that changes in the environment, particularly warming seas, have done more to remove this species from the coast of Europe than overharvesting (Raybaud et al., 2013). This may also be the case for brown algae species, such as *Ascophyllum nodosum* and *Macrocystis pyrifera*, respectively, along the Northern US Atlantic and Pacific coasts and locations where the oceans are warming.

Irish moss (*Chondrus crispus*) is a red algae used in the production of carrageenan. It is found in the intertidal to shallow subtidal ocean near Nova Scotia, Canada. Plants can either be tetrasporic or gametophytic (consisting of male and female). As a whole, Irish moss populations in southwestern Nova Scotia are not considered to be under immediate threat from overharvesting or environmental factors. However, there are indications of site specific overharvesting, and harvesting pressure appears to be increasing. Irish moss is harvested manually with a rake. Canadian regulators have suggested establishing long term permanently closed control sites for evaluating impacts on standing stocks and ecosystem effects; re-evaluating *Chondrus* standing stock for evidence of overharvest in specific areas; enforcing the 5 mm minimum rake tine spacing throughout Nova Scotia to prevent over harvesting; re-evaluating the Marine Plant Harvesting seasonal closure time to adequately protect periods of peak growth and reproductive effort, as well as seasonal habitat use of associated animals; and scientifically assessing any new harvest methods against consistent criteria prior to implementation for protecting Irish moss populations in Nova Scotia (Canadian Science Advisory Secretariat, 2013).

Nova Scotia maintains a commercial yield of rockweed. There still isn't sufficient information or analysis from industry or third party research proving that their harvest rate is not detrimental to the habitat value that rockweed provides to associated plants and animals. Estimated recovery times based on percentages removed vary between publications. Regulators have recommended actions for protecting rockweed populations in Nova Scotia including establishing long term, permanently closed control sites for evaluating impacts on standing stocks and ecosystem effects; re-evaluating *Ascophyllum* standing stock for evidence of overharvest in specific areas; replacing the regulated minimum cutting height of 12.7 cm with a minimum plant cutting height of 1 inch for all parts of Nova Scotia; revisiting the current provincial rule of 15% holdfast content in rockweed landings; scientifically assessing new harvesting methods (e.g. mechanical harvesters) prior to implementation (i.e. commercial use); and re-evaluating the need for seasonal closures to adequately protect periods of peak growth and reproductive effort, as well as seasonal habitat use of associated animals. Shore based walk-on harvesting of *Ascophyllum*, considered a high risk activity due to trampling damage to the plants themselves and associated biota plus the relative ease of attaining very high harvest rates, must also be examined for the potential of overharvesting (Canadian Science Advisory Secretariat, 2013).

Distributions of similar algal species can naturally vary geographically and over time. Habitat change producing conditions not well tolerated by resident species, can often lead to colonization by new species. Lack of competition or their inability to adjust to environmental changes can lead to the disappearance of one resident species from a particular region and replacement by another. Sometimes, the algae themselves cause these changing conditions. Many of the invasive algal species produce alien biomolecules that control competitive organisms in the new habitat. This is the case with the macroalga *Caulerpa taxifola* and *Undaria pinnatifida* (Wakame) which are green and brown macrophytes, respectively. Both species use chemical invasion to invade and colonize new habitats: inhibiting predation by herbivores; inhibiting growth of other marine plants and sometimes killing neighboring plants and animals (Mollo et al., 2015). In addition to chemical ecology, planktonic algal sporophytes and gametes spread by sea animals, currents, or by ocean-going vessels can competitively colonize new ocean regions where ocean temperatures, raised by global warming, are no longer suitable for the current resident species (Hoffman, 2014).

NOSB Question #3. Selective harvesting: There are about 6,500 species of red algae (Rhodophyta) such as Chondrus species, Palmiria, Delessaria; about 2,000 species of brown algae (Phaeophyta) such as Laminaria species, Ascophyllum species, Sacharina, Fucus, Sargassum muticum; and about 1,500 green algae (Chlorophyta) such as Dunaliella, of which many are not marine. How many species of each class are being wild harvested? Can one species be harvested without impacting other species in the same location?

Taxonomic revision amongst algal species has become commonplace. Morphologically plastic species in the same geographical area and identical species in different geographical locations are frequently given different specific names, while morphologically similar species with cryptic diversity are frequently given the same specific name (Saunders and McDevit, 2013; Pegg et al., 2015; Conklin, 2009; Kucera and Saunders, 2012). Thus, it is difficult to taxonomically evaluate diversity or species richness in the wildcrafting and aquaculture settings. Molecular technologies are making sense out of literally hundreds of years of misidentification; however, seaweed industries themselves provide transparency based on how specific plants are propagated and harvested.

Seaweed is prized in Japan for food and hydrocolloids. The Japanese actively manage and cultivate several species of seaweed along the coasts of Japan. Wakame (*Undaria pinnatifida*) is distributed in waters where the annual average surface water temperature is between 10 and 19 degrees centigrade. However, the greatest harvesting of Wakame in Japan occurs where the temperature is between 12-19 degrees centigrade. The agar-agar red algal seaweeds, *Gelidium amansii*, *Gelidium japonicum*, and *Acanthopeltis japonica,* are distributed primarily where the water is respectively, not less than 10, 16 and 17 degrees centigrade, slightly colder. Laver (Porphyra tenera) inhabits water with average temperature between 11 and 21 degrees centigrade (Endo and Matsudaira, 1990). Different species of algae grow best at different temperatures, lighting and nutrient concentrations (Gallardo, 2015). Aquaculturists in Japan recognized that macroalgal distribution and growth is species specific and affected critically by seasonal water temperature, lighting and nutrient fluctuations and have applied these as criteria for selecting which species to propagate and where and when to propagate them.

Water movement is a factor in the growth of seaweed. Practically, this applies to both ocean harvesting and pond or tank cultivation. In studies with the agar producing red algae *Gelidium robustum*, optimum water movement can contribute to 3.6% growth per day (Friedlander, 2008). Irradiance is critically important to the growth of seaweed. Marine algae adjust to sun and shade periods depending upon their abilities to photosynthesize. Some species and varieties of the same species are able to photosynthesize more or less depending on the particular light and temperature condition. Because photoproducts generate damaging free radicals, too much photosynthesis could harm the plant, but not having enough would result in insufficient growth. In addition, particular wavelengths of light are more suited for particular species and varieties of species. For example, *Gelidium sesquipedale* grows better under blue or red light (shade), than white light in controlled experiments. *Gelidium crinale* and *Gelidium pulchellum* grow well under ambient and bright light white light, respectively (Friedlander, 2008). Nitrogen, phosphate, dissolved inorganic carbon, and pH requirements also vary amongst macroalgal species. For wild harvesting, sea conditions dictate the species that grow in a particular location. The choice of cultivated seaweed species is important to ensure adequate performance for a particular set of conditions.

In a natural marine setting, ecological succession follows seasonal patterns. The first algae to colonize a habitat are the ephemeral species. These are followed by perennials. *Macrocystis pyrifera* (Kelp) and *Laminaria* spp. are perennials that displace ephemeral species. Their growth during ecological succession fosters growth for additional new algal and animal species. The important factors for recolonization are 1) availability of substratum for colonization, 2) species composition and abundance of reproductive material in the water at the time new substratum becomes available (assuming seasonal variation in colonization reflects a similar variation in reproduction), 3) similar growth rates of the new species that settle, and 4) the ability of the new species to invade established communities. Established communities, whether early or later stages in succession, appear to inhibit colonization by new species rather than enhancing it (Foster, 1975).

Dunaliella salina is a halotolerant green algae cultivated for production of β-carotene. Biologically this microalgae lacks a rigid cell wall and requires glycerol and β-carotene to maintain its osmotic balance. Under large scale culture in ponds or tanks this characteristic is easily exploited for a wide variety of applications (Raja et. al., 2007). Grown under high salinity condition *Dunaliella* accumulates glycerol. Irradiance stress induces the production of large amounts of β-carotene that prevents the accumulation of reactive oxygen species formed during photosynthesis. Biologically produced β-carotene from *Dunaliella salina* is in demand despite the predominance of commercial β-carotene derived from synthetic sources (Raja et al., 2007).

Kappaphycus is mostly farmed in tropical and subtropical oceans. It is the main source of kappa carrageenan. Cultivation of *Kappaphycus,* which has mostly displaced wild-gathered *Chondrus crispus,* is a major source of kappa carrageenan in the Philippines and other tropical countries. The cost of labor is lower in aquaculture. The geographical location of the Philippines, Indonesia, and Malaysia provide the right climate for *Kappaphycus* and permit profitable production of crops in spite of storms that disturb growth and harvest (Hurtado et al., 2015).

Kappaphycus and *Euchema* are good examples for the confusing nomenclature of algal species. The earliest identification of kappa-producing seaweed was called *Eucheuma cottonii*. This name was changed in 1985 when three new varieties of *Eucheuma alvarezii* var. *alvarezi*i, *Eucheuma alvarezii* var. *tambalang*, and *Eucheuma alvarezii* var. *ajak-assi* were identified based on external and internal morphology of the vegetative and reproductive structures of each variety. In 1988, all the three names were changed to *Kappaphycus alvarezii* var. *alvarezii*, *Kappaphycus alvarezii* var. *tambalang* and *Kappaphycus alvarezii* var. *ajak-assi*, respectively. At the present time, only *Kappaphycus alvarezii* var. *tambalang* is gown by farmers for commercial cultivation, because it is a fast growing species. There are still a number of *Euchema* species and the literature still has many references to "cottoni, "*Euchema cottoni* and Kappaphycus. Many different color morphotypes of *Kappaphycus* have been identified and the native tongue of each locality adds more confusion to the scientific nomenclature. Molecular taxonomy and systematics using genetic markers have recently been applied to the identification of seaweeds. In one study, one hundred and thirty seven samples of *K. alvarezii*, *K. striatum*, and *Eucheuma denticulatum* from Hawaii, Indonesia, Madagascar, the

Philippines, Tanzania, Venezuela, and Vietnam had similar mitochondrial cox 2-3 and plastidal RuBisCo spacers indicating that all cultivated *K. alvarezii* from around the world have similar mitochondrial and chloroplast haplotypes. Unfortunately, these markers did not differentiate all the morphotypes known in cultivated *K. alvarezii* (Hurtado et al., 2015). Morphological variations in color and shape can be the result of environmental influences on the same species. Naming can also be associated with geographical reference for a variety or species and the name of the phylogenist. It follows that many of the naming conventions may be duplicative or redundant.

This concept is illustrated in Table 5 where the authors have compiled all of the species of algae throughout the world, their actual use and the country of origin. The table includes 221 species: 32 Chlorphytes (green), 125 Rhodophytes (Red) and 64 Phaeophytes (Brown). The predominant uses are for food, phycocolloid production, agricultural inputs and animal feed. Many of the separate species names are for the same species, e.g. *Eucheuma alvarezii*, *Kappaphycus alvarezii* and *Kappaphycus cottonii* (Zemke-White and Ohno, 1999). As more is known about the polymorphic nature of the algae and molecular techniques are used to better elucidate genomic differences, a clearer understanding of the diversity in algal phylogenetics will likely emerge.

Table 5 Algal species used for economic purposes*

(Format of entries — Species |Use (F, A, C, Al, M, RoK, Ag or P) |Country of Origin)

F = Food, A = Agar, C = Carrageenan, Al = Alginate, M = medicine, RoK = Roe on Kelp, Ag = Agricultural, P = paper

Species	***Use***	***Country of origin***
Chlorophyta		
Acetabularia major	M	Indonesia, Philippines
Capspsiphon fulvescens	F	Korea
Caulerpa spp.	F	Malaysia, Thailand
Caulerpa lentillifera	F/M	Philippines
Caulerpa peltata	F/M	Philippines
Caulerpa racemosa	F	Bangladesh, Japan, Philippines, South Pacific Islands, Vietnam
	M	Philippines
Caulerpa sertularioides	F/M	Philippines
Caulerpa taxifolia	F/M	Philippines
Codium spp.	F	Argentina
Codium bartletti	F	Philippines
Codium edule	F	Philippines
Codium fragile	F	Korea, Philippines
Codium muelleri	F	Hawaii
Codium taylori	F	Israel
Codium tenue	F	Indonesia
Codium tomentosum	F	Indonesia
Colpomenia sinuosa	F	Philippines
Dictyosphaeria cavernosa	Ag	Kenya
	M	Philippines
Enteromorpha spp.	Ag	Portugal
	F	Bangladesh, France, Hawaii, Myanmar
Enteromorpha compressa	F	Korea, Indonesia
	M	Indonesia, Philippines
Enteromorpha clathrata	F	Korea
Enteromorpha grevillei	F	Korea
Enteromorpha intestinalis	F	Indonesia, Japan, Korea
	M	Indonesia

Species	Use	Country of origin
Enteromorpha linza	F	Korea
Enteromorpha nitidum	F	Korea
Enteromorpha prolifera	F	Indonesia, Japan, Korea, Philippines
	M	Indonesia
Monostroma nitidum	F	Japan
Scytosiphon lomentaria	F	Korea France
Ulva spp.	Ag	Italy, Portugal
	F	Argentina, Canada, Chile, Hawaii, Japan, Malaysia
	P	Italy
Ulva lactuca	F	Vietnam, Indonesia
Ulva pertusa	M	Philippines
Ulva reticulata	F	Vietnam
Rhodophyta		
Acanthophora spicifera	C	Vietnam
	F	Philippines, Vietnam
Ahnfeltia plicata	Ag	Chile
Asparagopsis taxiformis	F	Hawaii, Indonesia;
	M	Philippines
Betaphycus gelatinum	F/C	Vietnam
Calaglossa adnata	F	Indonesia
Calaglossa leprieurii	M	Indonesia, Vietnam
Catenella spp.	F	Myanmar
Chondria crassicaulis	F	Korea
Chondrus crispus	C	France, Spain, US
	F	Ireland, France
Chondrus ocellatus	F	Japan
Eucheuma alvarezii	C	Malaysia, Kiribati

Species	Use	Country of origin
Eucheuma cartilagineum	F	Japan
Eucheuma denticulatum	C	Philippines, Madagascar
Eucheuma gelatinae	C	China, Indonesia, Philippines
	F	Indonesia, Japan, Philippines
Eucheuma isiforme	F	Caribbean
Eucheuma muricatum	F/M	Indonesia
Eucheuma striatum	C	Madagascar
Gelidiella acerosa	A	India, Malaysia, Vietnam
	F	Philippines
Gelidiella tenuissima	F	Bangladesh
Gelidium spp.	A	China, Japan
	F	Hawaii
Gelidium abbottiorum	A	South Africa
Gelidium anansii	F/M	Korea, Indonesia
Gelidium capense	A	South Africa
Gelidium chilense	A	Chile
Gelidium latifolium	A	Spain
	F	Indonesia
Gelidium lingulatum	A	Chile
Gelidium madagascariense	A	Masagascar
Gelidium pristoides	A	South Africa
Gelidium pteridifolium	A	South Africa
Gelidium pusillum	F	Bangladesh
Gelidium robustum	A	Mexico
Gelidium rex	A	Chile
Gelidium sesquipedale	A	Morocco, Portugal, Spain
Gelidium vagum	A	Canada

Species	Use	Country of origin
Gigartina canaliculata	C	Mexico,
Gigartina chamissoi	C	Peru, Chile
Gigartina intermedia	C	Vietnam
Gigartina scottsbergii	C	Argentina, Chile
Gloiopeltis spp.	F	Vietnam
Gloiopeltis furcata	F	Korea
	C	Japan
Gloiopeltis tenax	C	Japan
	F	Korea
Gloiopeltis complanata	C	Japan
Gracilaria spp.	Ag	Portugal
	C	Malaysia
	F	Myanmar, Thailand
	P	Italy
	M	Vietnam
Gracilaria asisatica	A	China, Vietnam
	F	Vietnam
Gracilaria bursa-pastoris	F	Japan
Gracilaria caudata	A	Brazil
Gracilaria changii	F	Thailand
Gracilaria chilensis	A	Chile
	Ag	New Zealand
Gracilaria cornea	A	Brazil
	F	Caribbean
Gracilaria coronopifera	F	Hawaii, Vietnam
Gracilaria crassissima	F	Caribbean
Gracilaria domingensis	F	Brazil, Caribbean, Chile
Gracilaria edulis	A	India

Species	Use	Country of origin
Gracilaria eucheumoides	F	Indonesia, Vietnam
	M	Indonesia
Gracilaria firma	A	Philippines, Vietnam
	C	Philippines
	F	Vietnam
Gracilaria fisheri	A/F	Thailand
Gracilaria folifera	A	India
Gracilaria gracilis	A	Namibia, South Africa
Gracilaria heteroclada	A	Philippines, Vietnam
	F	Vietnam
Gracilaria howei	A	Peru
Gracilaria lemaneiformis	A	Mexico, Peru
	F	Japan
Gracilaria longa	A	Italy
Gracilaria pacifica	A	Canada
Gracilaria parvispora	F	Hawaii
Gracilaria salicornia	A	Thailand
	F	Thailand, Vietnam
Gracilaria tenuistipitata var. liui.	A	China, Philippines, Thailand, Vietnam
	F	Thailand, Vietnam
Gracilaria verrucosa	A	Argentina, Egypt, Italy
	F	France, Indonesia, Japan, Korea
	M	Indonesia
Gracilariopsis lemaneiformis	A	Canada
Gracilariopsis tenuifrons	A	Brazil

Species	Use	Country of origin
Grateloupia filicina	F	Indonesia, Japan
Gymnogongrus furcellatus	C	Chile
Halymenia spp.	F	Myanmar
Halymenia discoidea	F	Bangladesh
Halymenia durvillaei	F	Philippines
Halymenia venusta	Ag	Kenya
Hypnea spp.	F	Myanmar
Hypnea musciformis	C	Brazil
Hypnea muscoides	C/F	Vietnam
Hypnea nidifica	F	Hawaii
Hypnea pannosa	F	Bangladesh, Philippines
Hypnea valentiae	C/F	Vietnam
Iridaea ciliata	C	Chile
Iridaea edulis	F	Iceland
Iridaea laminarioides	C	Chile
Iridaea membranacea	C	Chile
Kappaphycus alvarezii	C	Philippines, Tanzania
	F	Philippines
Kappaphycus cottonii	C/F/M	Vietnam
Laurencia obtusa	F/M	Indonesia
Laurencia papillosa	Ag	Kenya, Philippines
Laurencia pinnitifida	F	Portugal
Lithothamnion corallioides	Ag	France, Ireland, UK
Mastocarpus papillatus	C	Chile
Mastocarpus stellatus	C	Portugal, Spain
	F	Ireland
Mazzaella splendens	A/F	Canada
Meristotheca papulosa	F	Japan

Species	Use	Country of origin
Meristotheca procumbens	F	South Pacific Islands
Nemalion vericulare	F	Korea
Palmaria hecatensis	F	Canada
Palmaria mollis	F	Canada
Palmaria palmata	F	Canada, France, Iceland, Ireland, UK, US
Phymatolithon calcareum	Ag	France, Ireland, UK
Porphyra spp.	F	Israel, New Zealand, UK
Porphyra abbottae	F	Alaska, Canada
Porphyra acanthophora	F	Brazil
Porphyra atropurpurae	F/M	Indonesia
Porphyra columbina	F	Argentina, Chile, Peru
Porphyra crispata	F	Thailand, Vietnam
Porphyra fallax	F	Canada
Porphyra haitanensis	F	China
Porphyra kuniedae	F	Korea
Porphyra leucostica	F	Portugal
Porphyra perforata	F	Canada
Porphyra psuedolanceolata	F	Canada
Porphyra seriata	F	Korea
Porphyra spiralis	F	Brazil
Porphyra suborbiculata	F	Korea, Vietnam
Porphyra tenera	F	Japan, Korea
Porphyra torta	F	Alaska, Canada
Porphyra umbilicalis	F	France, US
Porphyra vietnamensis	F	Thailand
Porphyra yezoensis	F	China, Japan, Korea

Species	Use	Country of origin
Pterocladia capillacea	A	Portugal
	F	Korea
Scinaia moniliformis	F	Philippines
Solieria spp.	F	Myanmar
Pterocladia lucida	A	New Zealand
Phaeophyta		
Alaria crassifolia	F	Japan
Alaria fitulosa	Ag/F	Alaska
Alaria marginata	F	Canada
Alaria esculenta	F	Iceland, Ireland, US
Ascophyllum nodosum	Ag	France, Canada, China, Iceland, US
	Al	Ireland, Norway, UK
Cladosiphon okamuranus	F	Japan
Cystoseira barbata	Al	Egypt
Desmarestia spp.	RoK	Alaska
Durvillaea antarctica	F	Chile
Durvillaea potatorum	Al	Australia
Ecklonia cava	F	Japan
Ecklonia maxima	Ag	South Africa
Ecklonia stolonifera	F	Korea
Egregia menziesii	F	Canada
Fucus spp.	Ag	France
Fucus gardneri	Ag	Canada
	F, RoK	Alaska
Fucus serratus	Al	Ireland
	F	France
Fucus vesiculosus	Al	Ireland
	Co	Ireland

Species	Use	Country of origin
	F	France, Portugal
Hizikia fusiformis	F	Japan, Korea
Hydroclathrus clathratus	Ag	Philippines
	F	Bangladesh, Philippines
Laminaria angustata	F	Japan
Laminaria bongardiana	F/RoK	Alaska
Laminaria diabolica	F	Japan
Laminaria digitata	Al	France, Ireland
	F	Ireland
Laminaria groenlandica	F	Canada
Laminaria hyperborea	Al	Ireland, Norway, Spain, UK
Laminaria japonica	Al	China;
	F	China, Japan, Korea
Laminaria longicruris	F	US
Laminaria longissima	F	Japan
Laminaria ochroleuca	Al	Spain
Laminaria octotensis	F	Japan
Laminaria religiosa	F	Japan, Korea
Laminaria saccharina RoK Alaska	F	Alaska, Canada, Ireland
Laminaria setchelli	F	Canada
Laminaria schinzii	Ag	South Africa
Lessonia nigrescens	Al	Chile, Peru
Lessonia trabeculata	Al	Chile
Macrocystis integrifolia	Al	Peru
	RoK	Alaska, Canada
Macrocystis pyrifera	Ag	Australia
	Al	Chile, Mexico, Peru, US

Species	Use	Country of origin
	F	Argentina
	RoK	Alaska, US
Nemacystis decipiens	F	Japan
Nereocystis luetkaena	Ag	Alaska, Canada
	F	US
Pelvetia siliquosa	F	Korea
Postelsia spp.	F	US
Sargassum aquifolium	F	Indonesia
Sargassum crassifolium	Al	Vietnam
	F	Thailand
Sargassum spp.	Ag	Brazil, Vietnam
	Al	Vietnam
	F	Bangladesh, Hawaii, Malaysia, Myanmar, Philippines, Thailand, Vietnam
	M	Brazil, Vietnam
Sargassum filipendula	F	Egypt
Sargassum gramminifolium	Al	Vietnam
Sargassum henslowianum	Al	Vietnam

Species	Use	Country of origin
Sargassum horneri	F	Korea
Sargassum ilicifolium	Al	India
Sargassum mcclurei	Al	Vietnam
Sargassum myriocystum	Al	India
Sargassum oligosystum	F	Thailand
Sargassum polycystum	F	Indonesia, Thailand
	Al, M	Vietnam
Sargassum siliquosum	Al	Vietnam
	F, M	Indonesia
Sargassum wightii	Al	India
Sargassum vachelliannum	Al	Vietnam
Turbinaria spp.	Ag	Vietnam;
	M	Philippines
Turbinaria conoides	Al	India
Turbinaria decurrens	Al	India
Turbinaria ornata	Al	India
Undaria pinnitifida	F	Australia, China, France, Japan, Korea
Undaria peterseniana	F	Korea

*Table adapted from Zemke-White and Ohno, 1999

NOSB Question #4. Contamination: Seaweeds can sequester metal ions such as arsenic, lead, zinc and copper. What is the indication from the most recent scientific research on sequestration of heavy metals by marine algae? Is there a difference in sequestration between species of algae? Are there additional processing steps taken to reduce and control for heavy metal content from the raw seaweed material?

The algae have a large capacity to sorb metals. Numerous chemical groups may be responsible for metal biosorption by seaweeds e.g. carboxyl, sulphonate, hydroxyl and amino with their relative importance depending on factors such as the quantity of sites, their accessibility and the affinity between site and metal. The main metal binding mechanisms include ion-exchange and complex formation but these may differ according to biomass type, origin and the processing to which it has been subjected (Murphy et al., 2008). Algal components such as the phycocolloids that contain carboxyl, sulphonate, hydroxyl groups are most commonly involved in metal binding. Factors such as metal concentration, biomass, pH, temperature, cations, anions, and metabolic stage all play a role in the binding of metals to algae. Dead cells sorb better than living ones (Mehta and Gaur, 2005).

Zinc and copper are not generally considered “heavy metals.” The term “heavy metals” is used widely in the literature to refer to lead, cadmium and others, but it is not a scientific term. On the periodic table, elements in the first row are transition metals. They have a role in many biologically functions. Some examples are manganese, cobalt, iron and zinc.

Arsenic (As, atomic number=33) is a ubiquitous element occurring naturally in the earth's crust. Of all the naturally occurring elements arsenic ranks 20th, 14th in seawater and 12th in the human body. It was first isolated in 1250 A.D. Most sources of arsenic are naturally occurring. Arsenic pollution is produced through mining, burning fossil fuels and pesticide application. In seawater, the concentration of arsenic is usually less than 2 micrograms per liter. (Sharma and Sohn, 2009). Arsenic toxicity is related to its chemical form. Inorganic As is considered more toxic than the organic form. The toxicity resulting from arsenic exposure is considered to be linked to an imbalance between pro-oxidant and antioxidant homeostasis that results in oxidative stress. (Ventura-Lima et al., 2011).

Arsenic exists in four oxidation states, +V (arsenate), +III (arsenite), 0 (arsenic), and −III (arsine). Arsenite, arsenate, and their methylated derivatives are the most commonly occurring as compounds. Arsenosugars are considerably less toxic than these, but are commonly found in marine algae including species used in human food. Arsenosugars are also found in marine animals feeding on algae such as scallops and fish. Arsenobetaine (AB) is the most commonly reported arsenosugar in marine organisms, but it is virtually absent in freshwater organisms. In relation to the inorganic arsenic species, arsenosugars are relatively nontoxic to animals and humans. However, biotransformation of arsenosugars can result in production of toxic arsenicals. In humans arsenosugar biotransformation produces toxic dimethylarsenic acid (DMA) as a major metabolite (67%) in urine. Diethylarsinoylethanol and trimethylarsinic oxide have been found as other minor constituents of arsenic metabolites. Metabolism of arsenosugars yielded DMA in excreted urine samples of sheep fed with seaweed. Biotransformation of arsenicals in soil amended with the seaweed species, *Laminaria digitata* and *Fucus vesiculosus*, containing 85% total arsenic as arsenosugars produces DMA, arsenate, and arsenite (Sharma and Sohn, 2009). High concentrations of arsenosugars have been found in some seaweed species (e.g. *Hizikia fusiforme*) in which the concentration of arsenic was as high as 100 micrograms per gram. Urinary arsenic levels after Hiziki ingestion in humans was similar to individuals with hyperkeratosis and hyperpigmentation in regions endemic for arsenite poisoning; accordingly, long-term ingestion of Hiziki can cause arsenic poisoning (Besada et al., 2009).

Dulse (*Palmaria palmata*) is a red algae commonly found in cold Atlantic intertidal and shallow subtidal environments. It can be harvested wild or cultivated and grows on rocks or other seaweed species, e.g. kelp. Dulse is commonly consumed as food. As with many other algal species, dulse naturally accumulates low levels of arsenic. It is likely that an average portion of dulse will contain 5-10 micrograms of arsenic, well below 5% of most international maximum residue limits (MRL) for arsenic. Based on sampling in Europe, mercury, cadmium and lead absorption by dulse harvested from non-polluted water contained much less than 5% of the international MRL for these metals (Mouritsen et al., 2013).

Algal species are often used as biosensors for contamination with arsenic and heavy metals. Their analysis in heavy contaminated areas, particularly in agricultural soil, can be used to determine required bioremediation strategies (Singh et al., 2016).

The life-cycle of the seaweeds, their physiological behavior, their element accumulation patterns, and natural geochemical processes involved in the environmental production of different elements in the ocean affect the accumulation of particular metals. These parameters are also strongly species dependent. The capacity of algae to accumulate metals depends on a variety of factors, the two most relevant ones being the bioavailability of metals in the surrounding water and the uptake capacity of the algae. Uptake takes place in two ways: 1) concentration dependent, temperature, light, pH and age independent surface reaction in which metals are absorbed by algal surfaces through electrostatic attraction to negatives sites (main uptake mechanism for zinc) and 2) slower active uptake where metal ions are transported across the cell membrane into the cytoplasm. Active uptake is enzyme dependent, likely to be the mechanism for copper, manganese, selenium and nickel and temperature, light and age dependent. Metal concentrations are low in summer when growth rates are high and the accumulated metals are diluted, and high in winter when the metabolic processes slowdown (Besada et al., 2009).

Cadmium concentrations in various algal species throughout the world have been found to be variable. The cadmium concentration in red algae is generally higher than in brown algae or green algae. (Besada et al., 2009).

Algae samples taken from the St. Lawrence river, including brown algae (Ascophyllum nodosum, Fucus vesiculosus), red algae (Porphyra palmata) and green algae (Ulva lactura) and others analyzed in a study to determine food health risk were not found to contain dangerously high levels of mercury, arsenic, cadmium, cobalt, chromium, copper, iron, manganese, lead, and zinc levels. Green alga, *Ulva lactuca* and *Enteromorpha spp* showed the highest concentrations of cobalt, chromium, copper, and iron, while the brown algae *Fucus vesiculosus*, *Laminaria longicruris*, and *Fucus distichus* had the highest arsenic and cadmium levels. Arsenic partial speciation revealed that this element is found mostly as a nontoxic organic compound, i.e., arsenobetaine or arsenocholine. Levels were all well below safe levels set by the US EPA (Phaenuf et al., 1999). In general, algae collected from unpolluted areas contain safe levels of heavy metals, while algae that is collected from polluted areas are likely to contain elevated levels of heavy metals and other contaminants (Caliceti et al., 2002; Giusti, 2001; Al-Shwafi and Rushdi, 2008; Gaudry et al., 2007; Abdallah and Abdallah, 2007). Thus, increased pollution will lead to higher levels of arsenic and heavy metal in algae for human consumption (Kim and Wolt, 2011).

NOSB Question #5. Organic certified Wildcrafting: Which marine algal species are being harvested under the "wild crafting" Organic standard, and in which geographic locations?

Section §205.207 of the National organic standard is for wild-crop harvesting practice or wildcrafting. It provides that a wild crop that is intended to be sold, labeled, or represented as organic must be harvested from a designated area that has had no prohibited substance, as set forth in § 205.105, applied to it for a period of 3 years immediately preceding the harvest of the wild crop, and (b) a wild crop must be harvested in a manner that ensures that such harvesting or gathering will not be destructive to the environment and will sustain the growth and production of the wild crop. Subsequent guidance for §205.207 was provided in NOP 5022 *Guidance Wild Crop Harvesting*. Herein, operations may be certified for the wild-crop harvesting of species from a defined terrestrial or aquatic area described in an organic system plan (OSP) in a manner that maintains or improves the natural resources of the area. Eligible species can be plant or other non-animal species, such as mushrooms, kelp, or seaweed, that are fixed to a defined location by a species part, such as a root, holdfast, mycelial thread, rhizoid, or stolon. A distinction between crop and wild crop certification is made when any management technique other than sustainable harvesting is employed.

The USDA NOP Integrity database lists eight operations that are certified to produce algae, fresh seaweed, seaweed, calcareous algae and algae products under the wild crops scope certification. Three of these, Cerule, LLC, Klamath Algae Products and the New Algae Company located in Oregon produce blue-green algae (cyanobacteria), harvesting single celled blue-green algae from freshwater lakes. The blue green algae harvested (e.g. spirulina and other species) are not marine algae.

Aladermis Industria E Comercio Ltd. in Vitoria, Brazil harvests benthic coraline algae called *Mesophllum superpositum* and *Lithothamnium superpositum*. These are red algae species (Rhodophyta) that have a thick calcareous coating called a rhodolith (Fig. 2). The rhodolith is also called maerl. Maerl is a harvestable commodity that is usually dredged from the ocean floor. These red algae are responsible for building reefs in the ocean and ecologically sensitive. Not much is known about their diversity or the diversity of their ecological communities (Henriques et al., 2012). Rhodolith beds are found throughout the world, provide an oceanic carbon budget and are represented by many different species, although the taxonomy is not clear (Basso et al., 2011). These algae are found in communities that range from shallow to deep water; the deepest having been found in excess of 260 meters. They grow about twelve percent per day (Potin et al., 1990). The coralline alga are a good source of seaweed derived calcium that has been found to be GRAS by the FDA and is approved for use in organic production through the existing listing of nutrient minerals on the National List §205.605(b).

Nantong Haida aquatic food Co., Ltd produces nori and is certified to the wild crop standard. This company is located in Nantong, China. Nantong is at the center of much of China's Nori production. Nori is produced from Pyropia yezoensis, formerly Porphyra yezoensis, a widely distributed species of red algae. This algae has two growth stages, a diploid and a haploid phase, each with a different morphology. The haploid phase gametophyte is cultivated to produce Nori. Pyropia is one of the most improved strains and tremendous effort has gone into traditional breeding, mutagenesis and hybridization to develop improved varieties (Zhang et al., 2014). Although it is readily cultivated on nets, this species can also be wild harvested.

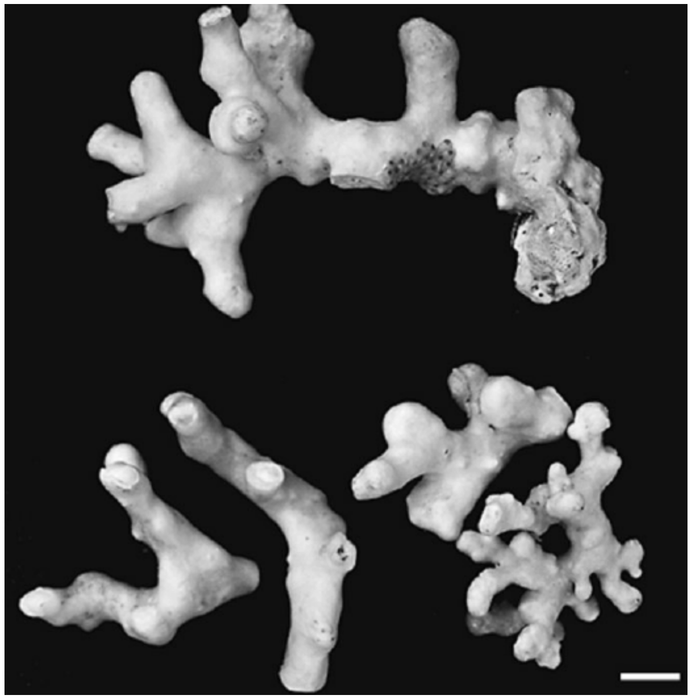


Fig. 2 Coraline Red Algae

from Henriques et al., 2012.

Euchemia cottoni, Gracilaria veruca, Gracillaria eucheumoides, Sargassum spp., Ulva lactuca are among 41 species recognized along the Vietnamese coast. These species are farmed, but may also be wildcrafted. There is one NOP certificate provide for Pure diets Vietnam Co., Ltd. Seaweed Project Ninh Thuan and Khanh Hoa in the Eastern sea, Khanh Hoa and Ninh Thuan province. These seaweed species are used for both food and phycocolloid production.

In Japan various kinds of food made from kelps are recognized as Kombu, one of the most important of the marine vegetable preparations. Kombu manufacturing dates back to 1730. Although now cultivated more than wild cropped, the gathering of kelp still provides employment for many people. The seaweeds used in the manufacture of Kombu are coarse, broad-fronded members of the kelp family (Laminariaceae), and were almost entirely from Hokkaido, the most northern of the main islands of the Japanese archipelago, until *Laminaria japonica* was introduced to the Chinese coast. The kelps grow in abundance on all parts of that coast, but those of best quality, that is, with the widest and thickest fronds, are obtained from the northeastern coast, within the influence of the Arctic current. Those most used are of the numerically large genus *Laminaria*, and include the species *japonica*, *religioisa*, *anoustata*, *lonqissima*, *ochotensis*, *yezoensis*, *fragilis*, *diabolica*, *gyrata*, and several others. Other kelps utilized in Kombu manufacture are *Arthrothamnus bifidus* and *kurilensis*, *Alaria fistulosa*, and various other species of *Alaria* (Smith, 1904). Since 1904, many of these species have been determined to be morphs of the same species or have been renamed.

The gathering of kelp begins in July and ends in October, and is engaged in by many fishermen. The fishermen go to the kelp grounds in open boats, each boat with one to three men and a complement of hooks with which the kelp is torn or twisted from its strong attachment on the rocky bottom (Fig 3). The hooks are of various patterns; some are attached to long wooden handles, and some are weighted and drugged on the bottom by means of ropes while the boats are under way (Smith, 1904).

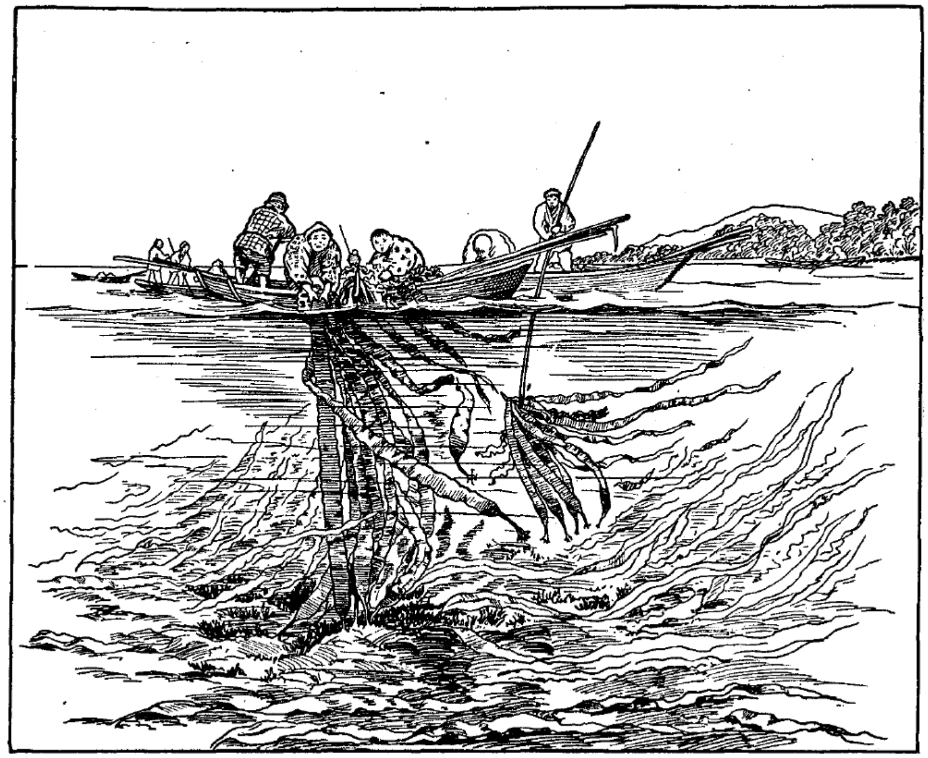


Fig 3. Gathering Kelp *from* Smith, 1904

In Argentina, several commercial species are wildcrafted and cultivated such as *Undaria pinnatifida*, *Gracilaria gracilis*, *Gracillaria verrucosa*, *Gigartina skottsbergii*, *Lessonia vadosa*, *Macrocystis pyrifera*, *Porphyra columbina*, *Ulva lactuca* and *Codium fragile* (Boraso de Zaixso, 1987; Rebours et al., 2014). In 1958, *G. gracilis* and *G. skottsbergii* were already harvested for the agar and carrageenan industries, respectively. Since 1980, *L. vadosa* and *M. pyrifera* have been exported to the USA and China to supply the alginate industry, and since 1999, the uses of the Argentinian seaweeds have expanded to new markets for human consumption, nutraceuticals, and cosmetics including the fucoidan industries. All seaweed is harvested in Patagonia, mostly in the provinces of Chubut and Santa Cruz. Local farmers directly sell the seaweeds to the processing companies or companies with concessions which directly employ their own workers for harvesting during the year and contracted divers in the summer. The harvest has been regulated since 1970 by the local government through special 3, 10, and 30 years licenses. Today, there is only one company (Soriano SA, Chubut, Argentina) producing agar and carrageenan. Soriano holds an NOP wild crop certificate for seaweed. The National Center of Patagonia (CENPAT) guarantees that the harvesting methods are performed in a sustainable way. Regulations for the management of brown seaweeds and marine concessions are particularly well developed, and the supply in brown seaweed to the alginate industry is well managed and organized (Rebours et al., 2014).

Thorverk hf. is an Icelandic company whose products include rockweed (Acophyllum nodosum) and kelp (Laminaria digitata). Mechanical harvesting uses specialized equipment and takes place between April and October. As with other areas where *Ascophyllum nodosum* and *Laminaria digitata* are harvested commercially, ecological concerns about changes in species diversity resulting from harvesting have been noted (Ingolfsson, 2010).

The vulnerability of seaweed as a resource has been shown a number of times in South America and Canada. Now, better management of shoreline resources is becoming prevalent for *Ascophyllum nodosum*, *Gracillaria* and *Laminaria spp*. It has become a priority for harvesters and regulators to recognize marine plants as a habitat and important primary producers and include this as a part of every management plan (Ugarte and Sharp, 2012).

NOSB Question #6. Cultivation: Which species are being cultivated, and in which geographic locations? What are the environmental issues associated with farming marine algae?

One company, Bold Coast Seaweed, LLC., located in Lubec, Maine, produces organic alaria, kelp, seaweed and dulse. This operation farms and/or harvests edible seaweed products including Alaria, kelp, Kombu, Tali and dulse, potentially from the brown alga, Alaria esculenta, *Laminaria digitata*, Laminaria hyperboea, Saccharina spp., Ascophyllum nodosum and the red algae, *Palmaria palmata*. Both of these species are readily cultured, however it is likely that these species are wild harvested in Maine. Another company in Maine certified for organic production of sea vegetables, including Algae (Alaria), Algae (Kelp), Algae (Seaweed), Dulse and wild crops is Maine Coast Sea Vegetables. This operation produces several additional algae species including Irish moss (*Chondrus cripsus*) and sea lettuce (*Ulva latuca*). As with the operations in Maine an operation in British Columbia, Outer Coast Seaweed produces Alaria and other seaweed, most likely kelp. These companies are likely to contract with local harvesters and farmers to purchase wild cropped or cultured crops for further processing. Seaweed farmers and harvesters in Maine and British Columbia are licensed and must abide by strict harvest rules to ensure the renewability of the seaweed crop. The use of seaweed has strong roots in China, Japan and the Republic of Korea (McHugh, 2003). Haian Lanbo Co., Ltd., Jangheung Musanim Co., Ltd., Kakunaka Co., Ltd. and Nantong Haida Aquatic Food Co., Ltd., respectively in China, the Republic of Korea, Japan and China are NOP certified producers of sea vegetables, seaweed and dried seaweed within the crops scope. These companies may contract directly with local farmers or a local fishery cooperative to obtain their crops each year.

In Indonesia, the Philippines, the United Republic of Tanzania, India, Mexico and the Solomon Islands carrageenan seaweed farming is profitable for coastal communities with abundant labor and few alternative activities (e.g. fisheries or tourism). A short production cycle, low capital requirement, and relatively simple farming technology are factors making carrageenan seaweed farming a means of poverty alleviation that is attractive to smallholder farmers or fishermen. Carrageenan seaweed farming also faces challenges that include storms, disease outbreaks, uncertain and fluctuating market conditions, competition from other sectors (e.g. fisheries, tourism and urban development), a lack of value-added products and value-adding activities in seaweed farming countries, low incomes of seaweed farmers in some countries, and occupational health hazards (Valderrama et al., 2013).

Seaweed farming is difficult work in along tropical coasts. In Zanzibar, Tanzania most seaweed farming is performed by women for the carrageenan producing seaweeds *Kappaphycus alvarezii* and various *Euchema denticulatum*. Farming takes place throughout the year and all of the product is exported (Fig 4). When the general health of seaweed farmers was compared with women involved in other activities it was found that seaweed farmers suffer greater health impacts than women who don't farm seaweed. These differences are likely to be the result of poor working conditions such as handling of heavy objects, intensive work and limited access to drinking water for long hours in combination with the exposure to strong sun, wind, seawater and toxic vapors. The most prominent health problems include general fatigue, musculoskeletal pains, hunger, respiratory and eye related problems, injuries from sharp shells and hazardous animals in the water, and allergies. Poor health has been reported by women of all ages and regardless of time spent on this activity, which shows that seaweed farming has negative impacts also in a shorter period of time. The income generated from seaweed farming in Zanzibar is very low in proportion to the workload. Most women work despite pregnancy or illness, which is most likely a consequence of poor living standards and the risk of losing important income (Frocklin et al., 2012).

In the Philippines the culture of the tropical seaweed species *Kappaphycus alvarezii* and *Eucheuma denticulatum* began in the 1960s, with commercial-scale production reached in 1971. Cottonii and Spinosum, respectively, are the commercial names of these two species. Both of these species support the carrageenan and phycocolloid industry and are now grown in the Phillipines, Indonesia, Tanzania, and Madagascar, with *Kappaphycus alvarezii* also grown in Vietnam and Malaysia. China, Indonesia and the Philippines culture most of the world's carrageenaophytes (Hurtado et al., 2013). From these regions combined come about 220, 000 metric tons of product. Seaweed farming is a good alternative to fishing in highly exploited fisheries. Farming takes place in the open ocean, sheltered bays and lagoons (Fig 5). Because there is an alternation in generations, gametophytes must be allowed to produce sporophytes (vegetative stage) that can be captured on ropes and in nets. The ropes and nets are suspended in the water and the algae product is permitted to grow. Another way is to set the sporophytes on rocks which are hurled into the farmed area. In the Philippines there is a close interaction between the farmers, and the buyers (Juanich, 1988; DeSan, 2012).

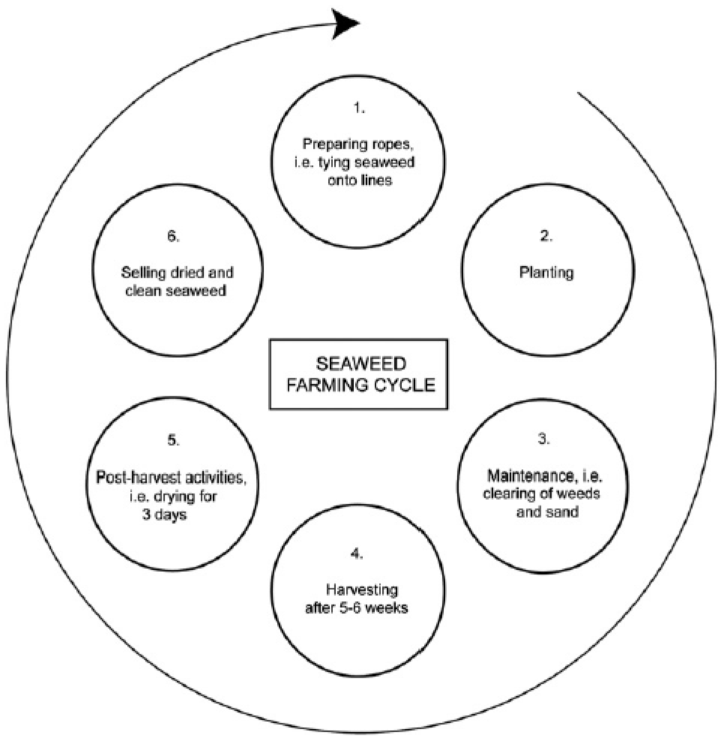


Fig. 4. The seaweed farming cycle in Zanzibar *from* Frocklin et al., 2012.

Seaweed culture is practiced using a number of distinct cultural methods and each of these methods impacts the environment in differently. For example, Gracilaria culture has been developed in abandoned shrimp ponds in the Philippines, Thailand and Indonesia, making use of otherwise wasted resources. In sea-based systems, large surface area requirements for viable seaweed culture in many areas could result in damage to coastal ecosystems and potential loss of some species of conservation interest, such as seagrasses. Large areas covered by *Laminaria japonica* culture in China influence coastal water movement and enhance sedimentation.

Fig. 54 Seaweed Farm in the Philippines *from* DeSan, 2012

However, the seaweed farm may also protect coastal areas from erosion and protect other sensitive species such as mussels or scallops. In shallow waters, seaweed farms for Gracilaria or Eucheuma can result in additional damage through trampling and accidental damage. Physical shading of an area by seaweed farms can affect benthic communities and primary production in the water column. The potential aesthetic impact of aquaculture has dominated arguments over aquaculture development in some countries and aquaculture planners must generally ensure potential aesthetic changes are considered during the development of new aquaculture ventures. Large surface areas required for economically viable seaweed culture can result in significant conflicts with users concerned with visual impact and others such as fishermen and tourists concerned with access (Phillips, 1990).

Seaweed culture requires a natural nutrient supply, which increases the potential to deplete coastal waters of nutrients. Reduced nutrient levels have been studied in *Laminaria japonica* culture areas. Nutrients diverted into macroalgae culture, rather than phytoplankton food chains, could affect patterns of nutrient recycling and secondary productivity. The removal of nutrients in high density culture areas also has implications for the long-term viability of seaweed farming itself. There are indications that over-intensified seaweed farming is resulting in outbreaks of disease and production losses. Some diseases in seaweeds may be linked to nutrient decline and over-intensification resulting in losses in Undaria and Porphyra culture. In some areas, nutrient depletion is reduced by fertilization. *Laminaria japonica* culture areas may be fertilized with inorganic fertilizers or manure when nitrate levels fall below 20 micrograms per liter. In intensive and semi-intensive aquaculture, various chemicals have been used for the prevention and control of disease, water treatment, removing predators and prevention of fouling organisms. Formaldehyde has been used for controlling the growth of epiphytes on Gracilaria and slaked lime has been used to control other predators. Concern has been raised over the potential impacts of such chemicals on the environment and the health of farm workers and consumers. Shading or smothering by large scale seaweed farming potentially reduces benthic productivity in shallow inshore areas. Increased sedimentation of organic matter from seaweeds and associated organisms can increase benthic production in areas with low current velocity, and there may be some community changes. The world-wide expansion in aquaculture has resulted in a very significant increase in the number of species of aquatic animals and plants which are moved beyond their native ranges for the purposes of aquaculture. These translocations carry the risk for potential adverse effect on aquaculture and wild species, either through introduction of new diseases or competition with native species. Seaweeds have also been accidentally or deliberately transplanted beyond their native range, with positive and negative impacts. *Laminaria japonica*, native to Japan was introduced to China, where it forms the basis of the largest seaweed industry in the world. *Sargassum muticum* and *Undaria pinnatifada* have spread throughout much of Western Europe, from Northern Spain to Sweden, and are now regarded as a major nuisance species in Western Europe causing significant problems to navigation in some areas (Phillips, 1990).

Laminaria japonica is a widely cultured brown algae in Japan and China. Ideally it grows in temperate cold water reefs. *L. japonica* exhibits alternation of generations as do many commercial algae species. The sporophyte generation or vegetative stage develops and releases male and female zoospores that swim around but eventually settle onto the substratum to form male and female gametophytes. In autumn, the female and male gametophytes respectively produce eggs and sperm that can fertilize them. The fertilized egg grows into a sporophyte or thallus. Culturing L. japonica is as follows: 1) selection of parent before general harvest, 2) drying stimulation and collecting zoospores, 3) seedling rearing, gametophyte generations, 4) your sporelings, 5) intermediate culture, 6) transplantation to ocean, 7) raft culture, 8) harvest (FAO, 1989).

To stem the effects of intense harvest of the giant kelp Macrocystis (integrifolia) in northern Chile, laboratory-grown juvenile sporophytes were fixed to different substrata (plastic grids, ceramic plates, or boulders) by elastic bands or fast-drying glue (cyanoacrylate). After reaching 150–200 cm in length within 5 months (relative growth rate≈1.3–1.7 % day−1), and reproductive maturity in 5–7 months seedling were placed at 8 m depth on the sea bottom in cotton gauze sleeves attached to boulders of different origin. Sixty percent of clean boulders collected on the beach produced up to seven recruits per boulder. In contrast, 20 % of the boulders from the sea bottom, colonized by epibionts, showed up to two recruits. Relative growth rates, however, were similar (≈2.4–2.6 % day−1). Laboratory grown seedlings can be used to establish new recruits on rocky substrata (Westermeier et al., 2014). In addition to efforts for maintaining Macrocyctis, culture of *Gracilaria chiliensis* remains a major cultivated species in Chile (Bushmann et al., 2005).

An integrated multitrophic aquaculture system for seaweed farming for human consumption in combination with mussel rafts was developed in Galicia (NW Spain). A productive marine farming system of *Saccharina latissima* ("sugar kelp") combined with mussel rafts was integrated in terms of harvest and protein content as well. Oceanographic conditions in Northwest Spain cause *S. latissima* to behave like a winter-spring species in culture with a growing period of just 5–6 months. Nonetheless, production values in this experiment equaled or exceeded those recorded in northern parts of the Atlantic where the culturing period is almost twice as long. Compared to natural populations, *S. latissima* from mussel-integrated culture systems had almost twice as much protein content, giving greater added value to the species both as food and feed (Freitas et al., 2015).

The red alga *Chondrus crispus* (Irish moss) has been commercially harvested in Eastern Canada for almost 60 years. Open-water aquaculture of cold-temperate species of carrageenophytes, and in particular of *C. crispus*, at Basin Head, in eastern Prince Edward Island (P.E.I.), and at 5 transplant sites in western P.E.I. Basin Head has been successful yielding productivity comparable, or even higher than wild cropping (Chopin et al., 1999).

Kelps in Spain are confined to northern temperate regions with relatively cold water, and the Iberian Peninsula (northern Spain and Portugal) represents the southern distribution limit of many species in Europe. *Undaria pinnatifida* (wakame) and *Saccharina latissima* (sugar kombu) are two of the most valuable seaweeds in northern Spain due to their high demand and economic value. The retail prices of wakame and sugar kombu are approximately 61–66 and 40–49 euros per kg dry weight of useful blade, respectively, in markets whose goods are intended for human consumption, which is their principal use today. Supply from wild harvest cannot meet increasing current and future demands and mariculture of these kelp species is a growing enterprise. On a commercial basis along the Atlantic coast of Europe, particularly in northern Spain, water movement is a key factor controlling the production and quality of kelp. *U. pinnatifida* is best cultured at more exposed sites rather than at sheltered sites, whereas both sheltered and exposed sites are suitable for S. latissima cultivation; hanging rope culture is best in sheltered areas, while horizontal rope culture is better suited for exposed locations. The fixed-pole anchor system for raft culture has been used successfully in exposed open-ocean sites as an alternative to the traditional system with concrete blocks; outplanting dates for the *U. pinnatifida* and *S. latissima* on the Atlantic coast of southern Europe are from October to November and from November to December, respectively. Harvesting is conducted from March to April and from April to May for these two outplanting seasons, respectively. Seawater temperature and seawater nitrogen concentration are the main determinants of the start and end of culture in the sea for both species. *S. latissima* is more economically and environmentally advantageous than *U. pinnatifida* (Peteiro et al., 2016).

On the Caribbean and Pacific coasts of Costa Rica an agriculture approach to cultivation of marine algae is under investigation for tropical countries wishing to add biodiversity, food and productive services to their economies. Species of Codium, Gracillaria and Sargassum can provide up to two crops per year and provide up to 15% (dry weight) substitutable food to farming families (Radulovich et al., 2015).

Especially in the hydrocolloid industry, sourcing seaweeds that are applicable for a particular products is very important. There has been a concerted effort in this industry to move from wild cropped species to cultivated species. For example in 1999 the readily cultivated *Laminaria spp.* from France, Ireland, the United kingdom and Norway represented only about 6% of the alginate seaweed harvest, but in 2009 it registered at 32%. In contrast, Macrocystis from the US, Mexico and Chile and Ascophyllum from France, Iceland, Ireland and the United Kingdom represented together represented 58% of the alginate seaweed harvest in 1999, but only 8% in 2009. To some extent this is due to market demand, but also to seaweed availability (McHugh, 2012).

NOSB Question #7. Carbon Dioxide (CO_2) sequestration: What does recent research indicate about the ability of marine algae to positively impact the environment, including global climate change, by their ability to absorb excessive CO_2?

In prehistoric times there was a stable balance between carbon dioxide in the atmosphere and reserves of biological and geological carbon. Now that we are actively using fuels and building new structures the balance is rapidly changing. The air is filling up with CO_2. Because CO_2 is toxic to us, the air is less breathable. Global warming is also increasing, since CO_2 is a heat trapping gas. The problem with the equilibrium is that processes releasing the additional carbon dioxide into the atmosphere e.g. burning fuel, building with concrete, removing forests, etc., are much faster than those that bind it into a non-atmospheric form. In our own history, since 1750, the beginning of the industrial era when the concentration of CO_2 in the atmosphere was 280 parts per million until today, CO_2 in the atmosphere has increased about 40% to 404 parts per million (Canadell et al., 2007; http://www.esrl.noaa.gov/gmd/ccgg/trends/). Some feel that more than 350 parts per million of CO_2 in the atmosphere is not safe for a sustainable earth (www.350.org).

There are four major carbon reservoirs on earth that can change in years or even centuries to bind carbon or release it as CO_2: fossil fuels, terrestrial ecosystems with vegetation and soils, the atmosphere and the oceans. Most gases are not very soluble in water, thus only about 1% of the world's oxygen is in the oceans. Because of the chemistry of seawater; however, 98.5% of the carbon in the ocean-atmosphere systems is in the sea (Houghton, 2007). The oceans can bind carbon with three natural pumps for taking CO_2 from the atmosphere. CO_2 dissolves in water to form bicarbonate, carbonate and undissociated CO_2. These products are called dissolved inorganic carbon (DIC). The solubility pump takes cold water with dissolved inorganic carbon down into the deep ocean: cold water sinks and warm water that rises becomes cold as a result of polar winter temperatures, again sinking and renewing the cycle. The polar regions of earth and cold coastal areas are the best places for this pump to work. The solubility pump accounts for about 25-40% of carbon sinking in the ocean. Thus, the intactness of the ice caps is recognized as an indicator of atmospheric CO_2 conditions (Arenas and Vaz-Pinto, 2015).

The carbonate pump relies on calcifying planktonic organisms such as coccolithphorides, cysts of dynoflagellates, formanifera and pteropods. Carbonates formed by these organisms fall to the bottom of the ocean (Shutland et al., 2013). The coralline algae participate in this pump.

The third pump is the biological pump. Photosynthesis drives this pump, taking solar energy, water and nutrients to convert oxidized inorganic carbon into energy rich organic carbon. In the ocean phytoplankton and other organisms contribute 15% of the carbon sinking of about two thirds of the dissolve organic carbon, called blue carbon and DIC (Arenas and Pinto, 2015). In fact, flow throughout the world of water currents containing carbon cycling from one or more pumps tends to drive seasonal changes in the biological pump (Behrenfeld, et al., 2009; Ritschard, 1992). At least half of the carbon captured in the ocean by the biological pump is linked to phytoplanktonic activity. Blue carbon, carbon captured at sea, is not exclusive to phytoplankton. Marine macrophytes including seagrasses and marine algae also have a role. Combined the macrophytes capture up to 2.5% of blue carbon. *Ascophyllum nodosum*, *Macrocystis integrafolia*, *Sargassum horneri*, *Postelsia capillaceae*, and *Ecklonia radiata* are all capable of capturing a substantial quantity of CO_2 (Arenas and Vaz-Pinto, 2015). Kelp forests can also serve as carbon sinks with substantial benefits. Afforesting 6% additional percent of the ocean floor with macroalgal farms and forests would provide enough carbon fixing to reduce 2026 anticipated atmospheric CO_2 of 430 parts per million to 350 parts per million. This can serve as testimony to harvesters and farmers that increasing the supply and use of marine algae has the potential to benefit the planet (Arenas and Vaz-Pinto, 2015).

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