FHIS Food & Health Innovation Service

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Sea Vegetables for Health

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Description and historic background

Sea vegetables, which are commonly referred to as algae or seaweed, have been a staple food since ancient times. Archaeological findings trace human seaweed consumption back to over 10,000 years ago. While, in ancient times, sea vegetables were widely consumed globally in countries located by the sea, including the U.K., Ireland, Norway, the Pacific Islands, African countries, and the Americas, in modern days, they have become primarily associated with Asian cuisine. Japan, which, today, has the world's largest seaweed consumption *per capita*, with 10-15% of the Japanese diet consisting of algae, is also associated with a significantly lower rate of cancer, thyroid diseases, heart disease and dementia than western cultures (Fitzgerald, Gallagher et al. 2011) (Venugopal 2011). The World Health Organization (WHO) estimates that in the EU alone, over 20 million people suffer from diabetes, that over 1 billion people in the world are overweight, and over 300 million people are obese, making obesity the most important factor for lifestyle-related diseases such as cardiovascular disease and cancer. In Europe alone, the economic costs associated with cardiovascular disease amount to €169 billion per year (Fitzgerald, Gallagher et al. 2011). The recent recognition that sea vegetables are a rich source of nutrients that can tackle these diseases has sparked a major interest in the use of sea vegetables as a food commodity (Venugopal 2011). In France, Ireland, Canada, and the United States in particular, there have been a strong movements to reintroduce sea vegetables into the local cuisine, and with the success of the industry, a wide range of cookery books incorporating recipes using sea vegetables have recently appeared on the market (FAO).

Algae grow primarily in the intertidal zone, and their constant need to protect themselves against oxidative stress from ultra-violet radiation, desiccation and extreme temperature fluctuations at low tide explains the abundance of potent anti-oxidants such as carotenoids, phlorotannins, ascorbic acid (vitamin C), tocopherol (vitamin E), polyphenols, chlorophyll derivatives, and mycosporine-like amino acids in seaweed. In comparison with terrestrial plants, algae are particularly rich in iodine, which is essential to the functioning of the thyroid and of the nervous system, in vitamin B_{12}, and in selenium. Overall, algae are rich in vitamins, minerals, proteins, poly-unsaturated fatty acids, and dietary fibers, and numerous clinical studies have demonstrated the health benefits of seaweed consumption and linked them to the nutrient composition of seaweed (Shahidi, Young et al. 2008; Venugopal 2011). In addition to their health benefits, seaweeds possess a wide range of important gastronomic and food-preservation properties (Kushi, Cunningham et al. 2001; Bocanegra, Bastida et al. 2009; Fitzgerald, Gallagher et al. 2011; Venugopal 2011).

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The health benefits of seaweed consumption include:

- the regulation of blood sugar levels and the prevention and treatment of diabetes
- the regulation of cholesterol levels
- a reduction in lipid absorption in the gastrointestinal tract
- weight loss and anti-obesity effects
- the prevention of hypertension
- the prevention of thrombosis and of excessive blood coagulation
- cardiac health improvement
- antioxidant effects
- the promotion of intestinal health
- the prevention and treatment of arthritis, asthma, rhinitis, gastric ulcers, and other inflammatory diseases
- the support of healthy joints
- the prevention of osteoporosis
- cancer preventive effects
- antiviral effects (against HIV and *Herpes simplex*)
- the promotion of a healthy thyroid function and the prevention of goitre
- prebiotic activities
- the regulation of bowel function
- the prevention and treatment of anaemia
- wound healing
- the regulation of hormone balance during menopause
- the detoxification from radioactive elements, heavy metals, and free radicals

Gastronomic and food-preservation properties of seaweed include:

- food thickening, emulsifying, and gelling properties (phycocolloids)
- vegetarian and vegan substitute for gelatin
- substitute for gluten
- natural food colouring
- foam stabilizing properties
- cryoprotection

- moisture preservation in meat and bread; retardation of bread staling
- aroma enhancement

Sea vegetables and their nutritional composition

Sea vegetables comprise the large macroalgae commonly seen on the seashore and microscopic, usually unicellular microalgae found ubiquitously in the water column down to a depth of 200 m.

Macroalgae are classified into three main groups: brown, red, and green algae. Brown algae, also known as kelp, tend to be very large and olive green or brown in colour. Their stem is attached to the substrate by a holdfast, and their blades grow up towards the water surface. Some brown algae possess gas-filled sacs and are free-floating. Red algae are typically smaller algae found in tidal pools. Their colours range from greenish to dark purple. Green algae are small and thin-layered algae found close to the water surface. They are particularly rich in chlorophyll a and b (Venugopal 2011).

Microalgae encompass unicellular green and red algae, cyanobacteria, diatoms, and dinoflagellates. Together, the microalgae form about 50% of the earth's primary biomass production and the base of the marine food chain (Venugopal 2011).

Brown macroalgae

Brown algae are generally rich in hydrocolloids, in iodine, and in pigments such as fucoxanthin and chlorophyll a and b. The abundance of phlorotannins and the carotenoid fucoxanthin is responsible for the anti-obesity and anti-diabetic properties of brown algae (Hosokawa, Miyashita et al. 2010; O'Sullivan, Murphy et al. 2010). The brown algae that are used for human consumption include *Alaria esculenta*, *Ascophyllum nodosum*, *Durvillaea* sp., *Ecklonia* sp., *Eisenia bicyclis*, *Fucus* sp., *Himanthalia elongate*, *Laminaria* sp., *Sargassum* sp., and *Undaria pinnatifida* (O'Sullivan, Murphy et al. 2010; Kim 2011; Venugopal 2011; FAO). Of these, *Alaria esculenta*, *Ascophyllum nodosum*, *Fucus* sp., *Himanthalia elongate*, *Laminaria* sp., and *Undaria pinnatifida* grow wildly on Scottish shores (ALGAEBASE 2012) (FAO ; MarLIN 2012). Rather than being consumed as fresh "vegetables", brown algae tend to be used under the form of dried sheets or flakes, ground seaweed flour, or purified phycocolloid extracts.

Alaria esculenta has a wide distribution in cold waters and does not survive above 16 °C. It is found primarily in Brittany (France), Norway, Russia, Canada, Hokkaido (Japan), Iceland, Ireland, and Scotland, where it is collected from the wild and eaten fresh or cooked by local people. *Alaria esculenta* is particularly rich in vitamin B_3 (niacin) and in proteins, which makes it satiating and highly nutritious (MarLIN 2012). *Ascophyllum nodosum* is rich in phycocolloids, including alginates, fucoidan, and laminarin, with a wide range of culinary applications, and with potent antithrombotic and anticoagulant activities. *Ascophyllum nodosum* is also a good source of mannitol (sugar-free sweetener), fucoxanthin, vitamin E, and phlorotannins (Ngo, Wijesekara et al. 2011). A blend of *Ascophyllum*-derived phlorotannins under the brand name ID-aLG^{TM} (Nexira, France), has been shown to decrease blood triclycerides and body fat amount in humans (Rajapakse and Kim 2011; Terpend, Bisson et al. 2011). All the remaining edible brown algae are rich in phycocolloids, and, in addition, *Fucus* sp. and *Laminaria* sp. are rich in antioxidant carotenoids and vitamin E, while *Eisenia bicyclis*, *Durvillaea antarctica*, and *Laminaria* sp, are rich in iodine, *Ecklonia* sp. is rich in phlorotannins, and *Eisenia bicyclis, Laminaria* sp., *Sargassum* sp., and *Undaria pinnatifida* contain a large proportion of proteins (MacArtain, Gill et al. 2007).

Red macroalgae

Red algae are particularly rich in phycocolloids (especially carrageenans) and in phycobiliproteins (Mabeau and Fleurence 1993; MacArtain, Gill et al. 2007; O'Sullivan, Murphy et al. 2010; Fitzgerald, Gallagher et al. 2011). They are often referred to as *agarophytes* or *carrageenophytes*, and they are widely used commercially for the production of thickening and gelling agents, prebiotic fibers, and food colourings (Fleurence 1999; Laurienzo 2010; Kim 2011). Red algae are also particularly rich in carotenoids and in B vitamins (Mabeau and Fleurence 1993). Edible red algae include *Chondrus crispus, Eucheuma denticulatum, Gelidium* sp., *Gigartina* sp., *Gracilaria* sp., *Kappaphycus alvarezii, Mastocarpus stellatus, Palmaria palmate,* and *Porphyra* sp. Of these, *Chondrus crispus, Mastocarpus stellatus, Palmaria palmate,* and *Porphyra* sp. are found on the Scottish shores, and *Gracilaria* sp. grows on the south coast of Wales (ALGAEBASE 2012) (FAO ; MarLIN 2012).

Porphyra is one of the most nutritious edible seaweeds due to its high abundance in proteins (up to 50% D.W.). It is the highest valued of all cultivated seaweed, at about U.S.$ 1200 per wet tonne, and it is the world's largest source of food from red algae (www.FAO.org). *Porphyra* is best known for its application as sushi wrap. *Gelidium* and *Gracilaria* alone account for most of the raw material used for the extraction of agar, while *Euchema denticulatum*, *Kappaphycus alvarezii*, and *Chondrus crispus* are the major commercial sources of carrageenans. *Mastocarpus stellatus*, which is a currently unexploited, is also a rich source of carrageenans (Venugopal 2011). *Palmaria palmate* is eaten fresh or sun-dried as snack, oven-baked with cheese, or as a condiment in soups, chowders, salads, spicy meat dishes, or pizza dough. *Palmaria palmate* powder is an iodine-rich flavourful substitute for monosodium glutamate (Kim 2011; Venugopal 2011).

Green macroalgae

Green algae tend to be found towards the top of the water column. They contain primarily chlorophyll and storage polysaccharides (O'Sullivan, Murphy et al. 2010; Kim 2011). Green algae are also rich in magnesium, calcium, iodine, and phosphorus (Mabeau and Fleurence 1993). Of the three genera of edible green algae *Ulva*, *Codium*, and *Caulerpa*, two, namely *Ulva* and *Codium*, grow along the Scottish coast (MarLIN 2012).

Ulva is found ubiquitously around the U.K (MarLIN 2012). It is rich in chlorophyll a and b, in vitamin C, and in ulvan and glucuronic acid which, despite their relatively low bioavailability, promote the synthesis of collagen and the formation of human cartilage (Mabeau and Fleurence 1993; Cooksley 2007). It is also rich in fucoidan, proteins (*esp*. lectins), beta-carotene, vitamin A, vitamin B complex, vitamin E, iron, and calcium (FAO 2012). *Ulva* can be eaten raw in a salad or added to soups and other savoury dishes as toasted flakes. *Codium* is attached to rocks in shallow rock pools. It is eaten raw, as a salad, and possess the earthy flavour of raw oysters. *C. lentillifera* and *C. racemosa* are the two most popular species of edible *Caulerpa*. They grow in warm waters around the Caribbean, Hawaii, and the Phillipines, and are found primarily on sandy or muddy sea bottom in shallow protected areas or saltwater ponds. *C. taxifolia*, which is native to the Indian Ocean but has also colonized the Mediterranean shores as an invasive species, is not suitable for human consumption. *C. lentillifera* and *C. racemosa* possess blood pressure regulating and antifungal properties. Both *C. lentillifera* and *C. racemosa* have a grape-like appearance and a very pleasant, slightly peppery taste. They are very popular in Hawaii and in the Philippines, where they are referred to as *green caviar* and consumed raw in salads. They can also be consumed cooked or in desserts (Ratana-Arporn and Chirapart 2006).

Microalgae

Microalgae are the largest primary biomass, covering 70 percent of the earth's surface to a depth up to 200 m (Venugopal 2011). They include diatoms, dinoflagellates, cyanobacteria, and microscopic green and red algae. Until recently, microalgae have been an untapped resource, but the recognition of their potential application for biofuel production and for protein and polyunsaturated fatty acid (PUFA) extraction for human food supplementation has led to a boom in the microalgae culture industry. Today, microalgae are cultured in large-scale open systems and in closed fermenters. The best known examples of edible microalgae are *Arthrospira* sp. (spirulina) and *Chlorella* sp. (Plaza, Herrero et al. 2009; Venugopal 2011). Spirulina consists up to 70% (D.W.) of proteins, 15% (D.W.) of carbohydrates (primarily rhamnose and glycogen), 10% (D.W.) of minerals, and only 5% (D.W.) of fats. In other words, spirulina is a low-fat, low-calories, virtually cholesterol-free source of proteins. Furthermore, the proteins found in spirulina comprise all of the essential amino acids, and, by being naturally stored as phycobiliprotein complexes, they have a high level of bioavailablity (Rimkus ; Fleurence 1999; Hendrikson 2011). With up to 20% phycocyanin, spirulina is nature' richest source of blue food colouring. Spirulina-derived phycocyanin is used in candies, soft drinks, ice cream, dairy products, and wasabi. Phycobiliproteins isolated from spirulina have been shown to possess hepatoprotective, anti-inflammatory, immunomodulating, antioxidant and anticancer properties. Spirulina doubles in biomass every 2-5 days, and it produces 400 times more protein than beef grown on the equivalent land area. 1g of spirulina contains as much vitamin as 1kg of fresh vegetables. It is 50 times richer in iron than spinach and 10 times richer in beta-carotenes than carrots. Studies have shown that a supplementation with spirulina ameliorates anaemia in senior citizens and in radiation-poisoned people, presumably through their high level of iron and of chlorophyll, a chlorin closely related to haemoglobin (Selmi, Leung et al. 2011). The lipid fraction of spirulina consists primarily of sulpholipids, which are known to inhibit the human immunodeficiency virus (HIV-1)(Gustafson, Cardellina et al. 1989) (Fleurence 1999; Plaza, Herrero et al. 2009). While spirulina possesses numerous health beneficial properties, it is critical to ensure that the harvested product has not been contaminated with cyanotoxins. Like other cyanobacteria, spirulina can occasionally produce cyanotoxins which, even at very low concentrations, are harmful to the human body. *Chlorella* is particularly rich in eicosapentaenoic acid (EPA), astaxanthin, and vitamin C. As such, it helps support a healthy immune system, blood pressure, and cholesterol level, and it prevents inflammation, cancer, psychiatric disorders, and cognitive aging (Lee, Choi et al. 2003). Other edible microalgae include *Cryptecodinium cohnii*, *Dunaliella* sp. *Haematococcus* sp., *Porphyridium* sp., *Shizochytrium* sp., and *Tetraselmis* sp. *Dunaliella* is a halophylic green microalga growing in saltmarshes. It is pink in colour due to its high levels of prebiotic beta-carotene and astaxanthin. *Dunaliella* is a fast growing microalga. It is particularly rich in oils (37% D.W.), especially docosahexaenoic acid (DHA). The remaining edible microalgae are cultivated primarily for their high levels of DHA.

Table 1. Major nutrients found in algae commonly used for human consumption

Official name	*Common name*	*Major types of nutrients*
Brown algae		
Alaria esculenta	dabberlocks, winged kelp	rich in proteins, vitamin B_3
Ascophyllum nodosum	rockweed, knotted wrack	rich in alginates (28% D.W.), in fucoidan (8% D.W.), in laminarin (7% D.W.), and in mannitol (7% D.W.); fucoxanthin, vitamin E
Durvillaea antarctica	-	rich in alginates, iodine, calcium, potassium, phosphorus, iron, vitamin A, B complex, C, D, E, and K
***Ecklonia* sp.**	-	alginates; fucoidan; eckol
Eisenia bicyclis	arame (Japan)	alginates; eisenin (tripeptide); vitamin A; iodine; calcium; iron; magnesium
Fucus serratus (and other *Fucus* species)	toothed wrack	rich in fucoidan (16% D.W.); fucoxanthin; beta-carotene, vitamin E
Himanthalia elongata	sea spaghetti, thongweed, *haricot de mer* (France)	fucoidan
Laminaria japonica (and other *Laminaria* species) *(main source of raw material for the alginate industry)*	*Saccharina japonica*, kelp, oarweed, kombu/kondu (Japan), haidai (China)	rich in alginates (32% D.W.), in laminarin (18% D.W.), in mannitol (14% D.W.), in proteins (10% D.W., incl. the amino acid taurine), in fucoidan (4% D.W.); iron; iodine; magnesium; calcium; fucoxanthin; beta-carotene;

		vitamin A, B_9 , C, D, E, K
***Macrocystis* sp.**	giant kelp, sea ivy	rich in alginates, mannitol, and vitamin E
***Sargassum* sp.**	limu kala (Hawaii)	alginates; fucoidan; mannitol (12% D.W.); taurine
Undaria pinnatifida	wakame (Japan)	rich in alginates (34% D.W.); in laminarin (3% D.W.); fucoidan; proteins (incl. the amino acid taurine); vitamin B_3, C, E

Red algae

Chondrus crispus	Irish moss	rich in carrageenans (kappa and lambda) (50% D.W.), floridoside (10% D.W.), and taurine (5% D.W.); beta-carotene; vitamin B complex
Eucheuma denticulatum *(commercial crop for carrageenan;* formerly *Euchema spinosum)*	spinosum	rich in carrageenans (*esp*. iota); lectins
***Gelidium* sp.**	limu lo-loa (Hawaii), hai tengusa (China)	rich in agar (30% D.W.)
***Gigartina* sp.**	-	rich in carrageenans (kappa)
***Gracilaria* sp.** *(major source of agar)*	ogo, ogonori (Japan), sea moss	rich in agar (25% D.W.); carrageenans; phycobiliproteins; lectins
Kappaphycus alvarezii (formerly *Eucheuma cottonii*)	cottonii	carrageenan (kappa) (22% D.W.)
Mastocarpus stellatus	carrageen moss	carrageenans (kappa and lambda)
Palmaria palmata	söl (Iceland), dulse	rich in floridoside (25% D.W.); iodine; carotenoids; vitamin B complex; taurine-

		rich proteins
***Porphyra* sp.**	nori (Japan), kim (Korea), laver, slawk	rich in proteins (up to 50% D.W., *incl*. the amino acid taurine), in porphyran (up to 45% D.W.), in floridoside (up to 40% D.W.), and in chlorophyll; beta-carotene; vitamin A, B complex, C, E; potassium; magnesium; iron

<u>Green Algae</u>

Caulerpa lentillifera	sea grapes, green caviar, umi-budo (Japan)	rich in iodine; phosphorus; calcium; magnesium
***Codium* sp.**	dead man's finger	lectins
Ulva lactuca (and *Ulva intestinalis)*	sea lettuce, green laver, anaori (Japan), limu palahalaha (Hawaii)	rich in ulvan (up to 55% D.W.), fucoidan, glucuronic acid, and iron; calcium; vitamin A, B complex, and E; proteins (up to 20% D.W.; *esp*. lectins); chlorophyll; beta-carotene

<u>Microalgae</u>

***Arthrospira* sp.** (cyanobacterium)	spirulina	rich in phycobiliproteins (up to 70% of D.W.); chlorophyll a and b (1% D.W.), vitamin B complex, and E; proteins; linolenic acid; beta-carotene
Chlorella (green alga)	-	rich in beta-glucan; beta-carotene; astaxanthin; vitamin C; chlorophyll (3% D.W.); EPA (40% of total lipids)
Crypthecodinium cohnii	-	high levels of PUFA (37%

(dinoflagellate)		D.W.), *esp*. DHA
***Dunaliella* sp.** (green alga)	-	rich in chlorophyll and beta-carotene
***Haematococcus* sp.** (green alga)	-	rich in astaxanthin and chlorophyll
***Porphyridium* sp.** (red alga)	-	rich in chlorophyll and phycobiliproteins
***Shizochytrium* sp.** (fungus-like microalga)	-	high level of PUFA, *esp*. DHA
***Tetraselmis* sp.** (green alga)	-	high level of PUFA, *esp*. DHA; chlorophyll; vitamin E

Health benefits and culinary applications of the compounds found in edible seaweed

Polysaccharides

The major polysaccharides found in algae are alginates, carrageenans, agars, fucanes, laminarans, ulvans, and floridean starch. These are referred to as phycocolloids due to their hydrocolloid properties: phycocolloids form gels in water by microscopic dispersion throughout the liquid solution. Phycocolloids have a wide range of biomedical and culinary applications (Plaza, Herrero et al. 2009; Venugopal 2011) (Mabeau and Fleurence 1993). The annual global production of phycocolloids is just under 100,000 tonnes, with a gross market value of US$ 1 billion/year. 80% of the global agar and carrageenan production and 30% of the global alginate production is used in the food industry (Kraan 2012).

Phycocolloids function as soluble dietary fibers. As such, they offer a wide range of beneficial physiological functions, including increased satiety, increased gut transit time, reduced cholesterol and glucose absorption in the gastrointestinal tract, and reduced risk of coronary heart disease (Fitzgerald, Gallagher et al. 2011; Venugopal 2011). A large proportion of the population in the Western world does not meet the recommended daily dietary fiber intake of 25 g, and, as a result, dietary fiber has become a lead ingredient in the food fortification industry (Fitzgerald, Gallagher et al. 2011). The average fiber content of red algae (6g per 100g of wet algae), is twice the amount found in fruits, vegetables, and cereals promoted today for their fiber content, such as prunes, cabbage, apples, and brown rice. In the food industry, algal polysaccharides are, thanks to their complex fibrous structures, excellent substitutes for gluten, which plays an important role in the firming of bread and pasta dough. Approximately 1% of the world population suffers from gluten sensitivity, and hence there is a high demand for gluten-free products, and finding suitable alternatives has proven to be very challenging (Venugopal 2011). Furthermore, the addition of algal polysaccharides to bread dough (0.1 % of the flour weight) has been shown to reduce the loss of moisture content during storage, and to retard staling (Kadam and Prabhasankar 2010). Algal polysaccharides can bind water at up to 20 times their own weight (Venugopal 2011). The water-binding properties of polysaccharides allow them to undergo gelation and form emulsions, and to stabilize foam in food and drinks (Venugopal 2011). The regular consumption of even small amounts of algal polysaccharides also has a major impact on the growth of beneficial probacteria such as bifidobacteria and lactobacilli. This places polysaccharide-rich algae into an excellent position on the €90 million-worth European prebiotics market (CEVA 2012). In the food industry, polysaccharides are used as emulsifiers in salad dressings, thickening agents in jams, sauces, syrups, and pie fillings, as swelling agents in processed meat products, as gelling agents in confectionery, jellies, pie fillings, and milk based desserts, and as foam stabilizers in beer (Venugopal 2011). Medicinally, algal polysaccharides have been shown to possess potent anticoagulant and antithrombotic properties (Luten 2009). Modifilan^{TM} (Pacific Standard Distributors, Inc.), a concentrated extract of *Laminaria japonica* containing alginates, fucoidans, and laminarin is marketed for the prevention and treatment of inflammation, coronary heart disease, cerebrovascular disease, cancer, and strontium intoxication (Kraan 2012).

Alginates, which include alginic acid, sodium, potassium, ammonium, calcium, and propylene glycol (food additives E400-E405), are found in the cell wall of *Laminaria* sp., *Himanthalia* sp., and *Ascophyllum nodosum*. Alginates reduce the absorption of cholesterol in the gut, promote wound healing, and inhibit the growth of cancer cells (Laurienzo 2010; Kraan 2012). One algal sodium alginate-based product, Appesat (Smart Shape^{TM}) has been approved as an appetite suppressing certified medical device in Europe. The culinary uses of alginates are based on four main physic-chemical properties: 1) the ability to form highly viscous solutions in acidic conditions, 2) the ability to instantly form heat-resistant gel spheres at room temperature through the addition of calcium or zinc to an aqueous solution of sodium alginate, 3) the ability to form non-sticky films and icings, and 4) the ability to protect food during freeze/thaw processes. Alginates can be easily blended into foods such as yogurts, creamy desserts, pasta, bread and pizza dough, and meat patties without any adverse effect on the taste or texture, to replace some of the fat content and to increase the fiber content, thereby boosting the products' healthiness (Venugopal 2011). Alginates are also used for the production of propylene glycol alginate (PGA) widely used as an emulsifier in ready-made sauces and salad dressings. PGA and alginates prevent the precipitation of fruit pulp or cocoa in drinks and yogurts, and they stabilize whipped cream and beer foam. Alginates are widely used in jams, ice cream, cake icing, restructured fish and meat and onion rings, and tooth paste (CEVA 2012; FAO 2012; Nutramara 2012). The use of alginates to treat gastritis, gastroduodenal ulcers, esophageal acid reflux, and epigastric burning has been patented by several companies around the world (Kraan 2012). Alginates represent an important market. Today, Europe is the largest alginate processor (16,000 tonnes, 44% of the worldwide capacity in tonnes), followed by Asia (43%) and the Americas (13%) (CEVA 2012; FAO 2012).

Carrageenan (E407) is a generic name for a complex family of sulfated polysaccharides found in a wide range of red algae (Laurienzo 2010). Carrageenans are water-soluble linear biopolymers. Industrially relevant carrageenans are classified into kappa-, iota-, and lambda carrageenan, based on their chemical composition and structure (Venugopal 2011; FAO 2012). Both kappa and iota carrageenan form gels with potassium and calcium salts, if the solution is heated to 60°C and allowed to cool down. Kappa carrageenan is a strong gelling agent, and only 0.5% (weight/volume) is required to form gels. With potassium, kappa carrageenan gels become rigid, whereas, in the presence of calcium, they become stiff and brittle. Kappa carrageenan gels are slightly opaque, but they become clear with the addition of sugar. Iota carrageenan gels are soft, elastic and clear. They are virtually free of liquid bleeding out of the gel, and they remain intact during freeze/thaw processes. Lambda carrageenans do not form gels, but they have strong thickening properties. In medicine, carrageenan is particularly valued for its microbicidal properties. Carrageenan has been clinically proven to inhibit human *Papilloma* virus (HPV). Carraguard™, a carrageenan-based candidate microbicide, has been shown clinically to reduce vaginal HPV infection. In the food industry, carrageenan has similar applications to alginates and agar. Carrageenan is used in dairy products, ice creams, baking industry, puddings, and sauces. Weak gels formed by the addition of small amounts of kappa or iota carrageenan allow the suspension of fine particles such as cocoa or herbs in the milk or low-fat salad dressings. In small quantities, lambda carrageenan prevents fat separation in evaporated milks. Carrageenan is also used as a pectin substitute in low calorie jams, as pectin has a weaker gelling strength in the absence of sugar. Like alginates and agar, carrageenan is used to manufacture a wide range of products, such as restructured fish or meat, to increase the palatability and the fiber content and to replace some of the fat content. Furthermore, the incorporation of carrageenan in the batter of fried seafood significantly reduces the oil absorption during flash frying which can, otherwise, be as high as 30% of the fried product's weight (Venugopal 2011; CEVA 2012; FAO 2012; Nutramara 2012).

Furcellaran, also known as Danish agar and found in red algae, is a highly sulphated polysaccharide composed primarily of D-galactose. The structure and properties of furcellaran are similar to the ones of kappa-carrageenan. Furcellaran (E408) is used as gelling agent, thickener, and stabilizer in drinks, custards, cake fillings, icings, and processed meat products such as patés and pastry fillings (Venugopal 2011). Porphyran is another galactan resembling agar. It is found in *Porphyra* sp. and it possesses anti-cancer, blood pressure lowering, and cholesterol lowering properties (Kraan 2012).

Fucoidans are polysaccharides composed primarily of sulphated L-fucose. Fucoidans stimulate both the innate and the adaptive immune system and prevent replication of viri, including HIV, herpes simplex virus, and poliovirus, by modifying cell surface properties (Kraan 2012). Fucoidans have also been shown to have potent antioxidant, anti-inflammatory, and anti-cancer properties. The fucoidan-based food supplement Modifilan™ (Pacific Standard Distributors, Inc.) is marketed for the prevention and treatment of inflammation, coronary heart disease, cerebrovascular disease, and cancer (Kraan 2012).

Ulvans are sulphated polysaccharides found in green algae and composed of rhamnose, xylose, glucose, uronic acid, glucuronic acid, and iduronic acid as main constituents. Ulvans are the only known plant source of the potent anti-coagulant iduronic acid (Kraan 2012). Ulvans play key roles in collagen synthesis and the formation of cartilage (Cooksley 2007).

Floridean starch is an amylopectin-like glucan isolated from red algae. It has a low gelling and pasting temperature, a high level of gel clarity, and a strong resistance to repetitive freeze-thaw processes, which makes it suitable for the preparation of instant noodles and deep-frozen food (Venugopal 2011).

Laminarin is a linear glucan found in the fronds of brown algae. Unlike other algal polysaccharides, laminarin does not have hydrocolloidal properties, but it is marketed for its beneficial effects on the human immune system. Laminarin shares the same antiviral properties as fucoidans, and food supplements aimed at boosting the immune system often contain a mixture of both laminarin and fucoidans (Kraan 2012).

Other carbohydrates

Mannitol, a sugar alcohol present in many species of brown algae, is used as a sugar-free sweetener by diabetics and low-GI dieters. Mannitol has less food energy than regular sugars such as sucrose and, like other sugar alcohols, mannitol is incompletely absorbed into the blood stream from the small intestine. As a consequence, it has little effects on the blood glucose levels, and it acts as a mild laxative. As it is not metabolized by oral bacteria, mannitol does not contribute to tooth decay. Mannitol is widely used in sugar-free chocolates and chocolate-flavoured coatings. Mannitol is also used in chewing gum and candies to produce a cooling sensation in the mouth as the sugar alcohol dissolves from the hard crystalline phase. Furthermore, mannitol maintains stable moisture contents in foods and it increases the shelf-life of food (Kraan 2012).

Lipids

Overall, algae have very low lipid contents (as low as 0.3% D.W. in green algae), hence their popularity in weight loss diets. Furthermore, the lipid fraction of algae consists primarily of essential C18 polyunsaturated fatty acids (PUFAs) and long-chain PUFAs generally associated with health-beneficial fish oils (Shahidi, Young et al. 2008). Algae are particularly rich in omega-3 PUFAs. As such, they have an immense potential as health-beneficial adjunct to Western diets to decrease dietary omega-6-to-omega-3 ratios (resulting from the preponderance of oilseed omega-6 fatty acids in the diet) in a bid to reduce the risk of cardiovascular diseases, cancer, and chronic inflammatory and autoimmune diseases associated with excessive intake of omega-6 PUFAs (Simopoulos 2002; Shahidi, Young et al. 2008).Omega-3 PUFAs such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) commonly found in algae have been shown to have beneficial effects on cancer, inflammation, cardiovascular diseases, psychiatric disorders, and cognitive aging (Shahidi, Young et al. 2008).

Peptides and proteins

Taurine, or 2-aminoethanesulfonic acid, occurs naturally in meat and seafood, and it is particularly abundant in brown and red algae. Taurine is essential for cardiovascular, central nervous system, and retina function, and for skeletal muscle development. Taurine supplementation may be particularly beneficial for vegans and for formula-fed premature babies (Shahidi, Young et al. 2008). The tripeptide eisenin (L-pyroGlu-L-Gln-L-Ala) found in the brown alga *Eisenia* sp. and lectins, which are particularly abundant in red and green algae, are well known for their immunostimulatory effects, especially after radiotherapeutic cancer treatments (Shahidi, Young et al. 2008). Phycobiliproteins such as phycoerythrin and phycocyanin found in microalgae and in red algae are widely used in dietary supplements as anti-inflammatory, anti-cancer, neuroprotective, and hepatoprotective agents (Shahidi, Young et al. 2008).

Terpenoids and polyphenolics

Algae are rich in carotenoids such as fucoxanthin, asthaxanthin. Fucoxanthin and asthaxanthin are potent antioxidant, anti-inflammatory, anti-cancer, anti-diabetic, and anti-obesity agents. The anti-diabetic and anti-obesity properties derive from the compounds' ability to regulate a protein called thermogenin in white adipose tissue (Shahidi, Young et al. 2008; Lordan, Ross et al. 2011; CEVA 2012). Fucoxanthin is marketed as a weight loss supplement by AHD International under the name of Bellalean.

Algal phlorotannins, including eckol, dieckol, and phloroglucinol isolated from brown algae have anti-cancer properties through their interference with the carcinogenic enzyme hyaluronidase (CEVA 2012). They are also potent anti-thrombotic agents (Fukuyama, Kodama et al. 1989). A blend of brown algae-derived polyphenols marketed by Innovactiv (Canada) as InSea2™ significantly decreases blood glucose levels following high carbohydrate meals, as it interferes with the enzymes amylase and sucrase involved in the digestion and assimilation of carbohydrates.

Vitamins and minerals

Marine algae are a rich source of vitamins A, B_1, B_2, B_3, B_9, C, and E. Vitamins C, and E are potent antioxidants. Vitamin A plays an important role in cell growth and differentiation, and B vitamins are precursors for enzyme cofactors (Fukuyama, Kodama et al. 1989). Marine algae are also rich in iodine, iron, potassium, magnesium, calcium, selenium, and phosphorus – minerals that are widely used in health beneficial supplements. Iodine, in particular, plays an important role in the functioning of the thyroid (Fukuyama, Kodama et al. 1989).

Applications of seaweed in the food industry – current situation and future perspectives

Several ventures in Europe and around the world have shown that the production of sea vegetables for human consumption provides a wealth of exploitable marketing opportunities. The global human seaweed consumption is increasing exponentially and, with the rise in popularity, sea vegetables are gradually becoming more and more available in local shops. Numerous celebrity chefs and world-renowned restaurants all around the globe are boosting the integration of marine algae into their menus (Fleurence 1999; Fitzgerald, Gallagher et al. 2011; FAO). Recent surveys have shown that over two thirds of the general public in the western world have experienced eating algae at least once. The majority of these people have continued to consume seaweed, with their choice being primarily driven by the enjoyable taste and for health purposes. Algae, and seafood in general, is perceived by the British population as healthy food (Honkanen 2009; Edwards, Holdt et al. 2012). Two thirds of the people who have discontinued their consumption of seaweed have done so due a lack of product availability or lack of algae-related culinary knowledge (Edwards, Holdt et al. 2012). In response to this problem, international algae recipe competitions have been launched. The 2011 International Algae competition (www.algaecompetition.com) received hundreds of recipe ideas giving traditional meals from around the world, such as lasagna, shrimp bisque, guacomole, quiche, tacos al pastor, sherbet, lemon meringue pie, chocolate truffles, and smoothies, just to name a few, an algal touch. The event has been regarded as a great success. The U.K. is following the global trend of increased algal consumption. Sushi Trade U.K. (www.sushitrade.co.uk) has reported a 21% annual increase in sushi consumption in the U.K. (30% in Scotland) in the recent years, and a BBC home vote cast for the Children's BBC news program *Healthyliving* has shown almost 60% of the British population would like to eat more sea vegetables and would consider eating seaweed products such as seaweed burgers. The market of carotenoids isolated from microalgae is expected to increase steadily over the next few decades, based on a survey performed by TecKnowMetrix for Algasud in the context of the IEED Green Stars Project. To match the demand in microalgae and seaweed for human consumption, algal culture centres are set up and expanded all around the world. Seambiotic (Israel) and Maris (Netherlands and Indonesia) are amongst the world leaders in microalgae culture.

Applications of marine algae and of natural products isolated thereof in the food industry are listed in table 2.

Table 2. Applications of marine algae in the food industry

Application	Company	Country
Seaspice collection: - *Celtic Kombu* - *Pepper dulse* - *Shony Flakes*	Mara	Scotland

- *Sea lettuce emerald shavings* - *Dulse* (used by celebrity chefs, and awarded the 2012 *Great Taste* Gold Award (UK)		
Seasalt with seaweed flakes	various	various
Saloni K salt (seaweed-derived salt substitute for hypertensive patients)	NMS Pharma	India
Just Seaweed (fresh, dried, and crushed algae from the Isle of Bute)	Just Seaweed	Scotland
Bod Ayre organic seaweed sprinkle	Seaweed Products	Scotland
Seaweed and microalgae (fresh/dried)	Ardtoe Marine Laboratory	Scotland
Seaweed as fresh vegetable, dried flakes, dried sheets, or condiment	various	worldwide
Pasta with 10% wakame in the dough (improves the sensory characteristics of pasta by enhances the gluten network within the dough) or fortified with algal PUFAs to boost the consumption of omega-3 PUFAs	various	various
Algal extracts as natural food colourings: phycobiliproteins and astaxanthin are widely used in salmon aquaculture, zeaxanthin, lutein and canthaxanthin are used in chicken skin colouring (BASF Health & Nutrition estimates the global carotenoid business at over 1 billion US $)	various	wordwide
Infant formula milk containing algae-derived DHA	Martek	USA
Algalin (lipid replacement powder used in cooking, baking, and ice cream confection to reduce the calorie uptake by up to 50%, and to extend the shelf life of certain foods	Solazyme Roquette Nutritionals	Germany
Pizzas fortified with seaweed (blended into the dough) (awarded the *Best New Idea* price at the 2012 Food & Drink Expo (UK))	Eat Balanced Ltd.	Scotland

Processed *Eucheuma* Seaweed (PES) and refined carrageenan (carrageenan-rich seaweed flour) (used in processed meat and fish and in Chinese egg noodles to improve the texture)	various	Philippines
Seaweed flavoured crisps	Pringles (Kellogg company)	Asia
Sea Veggies Snack	Yang Ban	U.S.A.
Lay's Stax crisps flavoured with nori	Pepsico	Thailand
Kelp Krunch snackbars and "Sea chips" (crisps)	Seaveg	U.S.A.
Crispy seaweed thins	Itsu	South Korea
Roasted seaweed snacks flavoured with wasabi and sesame	Annie Chun's Seaweed Snacks	U.S.A.
Spirulina-coated popcorn	Spirit First Food	U.S.A.
Corn snack seasoned with kombu and bonito flakes	Meiji	Japan
Spirulina energy bars	Go Raw	U.S.A.
Seaweed rice chips and rice cakes	Lundberg Farms Organic	Sweden
Croquin'Algue and Oliv'Algue luxury cereal bars with wakame	Laboratoires Daniel Jouvance	France
Wakamis raviolis filled 70% with wakame, 30% with salmon	Wakamer	France
Fish soupe with algae	Kerbriant; Algues de Bretagne	France
Tofu with tomato and algae sauce	LIMA Nature & Progrès	France
Algae taboulé	Maître Gourmeon	France
Tuna and algae salad ("salade océane")	Saupiquet Les repas fraîcheur	France
Instant rice porridge with pork and seaweed	Knorr	Asia
Chimi Churri salsa made with Gallician seaweed, garlic, and olive oil	Porto Muinos	Spain
Instant wakame soup sachets	Kikkoman	Japan
Paté of crab, scallops, and algae	Guyader deli "L'esprit de la mer"	France
Tartinalgue and Tartimer spreads	LRCB Côtes	France

	d'Armor	
Sweet/savoury "Perles saveur" alginate pearls for cocktails, canapés, starters, desserts,…	Algues de Bretagne	France
Carrageenan, agar, and alginates for "Molecular Gastronomy"	various	various
Aquamin algae-derived minerals specifically formulated to be added to baked products, processed meats, low-pH drinks, or frozen desserts	Marigot	U.S.A.
Chocolate, cherry & blue-green algae Qi snack bars	Superfood snacks	U.S.A.
Luxury chocolates with 70% wakame filling, and white chocolate coloured with algal dyes	Chocolalg	France
Chlorella jellies	Solazyme Roquette Nutritionals	Germany
Spirulina & Propolis honey; Chocolate with 10% spirulina	SPILA	Lithuania
Probiotic drink made from milk, *Lactobacillus casei* and Chlorella	Yakult	Japan/worldwide
Smoothies fortified with spirulina	Jamba Juice	U.S.A.
Algae-flavoured beer	Tonnerre de Brest	France
Liquors flavoured with algal aromas	Distillerie artisanale de Plessis	France

(sources of information: Handbook of marine macroalgae: Biotechnology and applied phycology (Kim 2011); personal communication with Dr. Maria Hayes (NutraMara, Teagasc Food Research Centre (Ireland) and with Dr. Craig Rose (Seaweeds for Health))

The algal food industry in the U.K.

The U.K. algae industry consists of around 15 small and medium sized enterprises (SMEs), including 10 SMEs focusing on human food products. The total amount of algae harvested in the U.K. is estimated at 12,000-15,000 tonnes per year. The main centres for wild shoreline harvesting in the U.K. are based around the Outer Hebrides, the Orkney Islands, Shetland, Northern Ireland, and South Wales. Pilot scale seaweed aquaculture farms and trial cultivation of *Saccharina latissima* and of *Laminaria hyberborea* are currently underway at several sites in Scotland. Together with the U.S.A. and Norway, the U.K. is one of the world's top three alginate producing and manufacturing countries – with a major production site in Ayreshire, Scotland (FMC BioPolymer) (Sanderson and Prendergast 2002). As mentioned above, algal consumption has grown in popularity amongst the British public. In order to continue to increase the awareness of the local public of the numerous health benefits of algal consumption, and to promote the availability of algal products in local food stores and on restaurant menus, a list of "ten excellent reasons to integrate seaweed consumption into your lifestyle" has been put together:

Ten reasons for consumers to integrate seaweed consumption into their lifestyle

1) Algae are of low calorific value and hence suitable food sources during weight loss and weight management diets.
2) Algae are suitable and complementary to vegetarian, vegan, and low calories diets, and conform to Kosher regulations (alginates, agar, and carrageenans are excellent gelling agent alternatives to gelatin). Algae provide vitamin B_{12} which tends to be low in vegan and vegetarian diets.
3) Algal products can be used as substitutes for gluten in gluten-free foods.
4) Algae are a rich source of iron and of iron bioavailability-enhancing vitamin C.
5) Algae are a rich source of iodine and hence have the ability to help prevent and treat hypothyroidism and to protect against health damage caused by nuclear radiation.
6) Algae have a low salt (NaCl) content and are a good salt substitute with rich sea salt-like flavours.
7) Algae possess numerous bioavailable nutraceutical compounds with health-beneficial properties including hypoglycemic, hypocholesterolemic, anti-obesity, cardioprotective, anti-oxidant, anti-inflammatory, anti-cancer, anti-viral, and immune-stimulant properties.
8) Algal products can be easily integrated into common food such as bakery products, pasta, etc. without affecting the taste or texture of the food.
9) Algae grow fast compared to agricultural plants, and they are well suited to the British climate. Algae grow in the ocean, solving issues of

freshwater supply and arable land availability, as the U.K. possesses a large coastal area.

10) Algae are low-cost, highly nutritional alternative to soy and other protein crops. They are also an environment-friendly alternative to tropical palm trees for cooking oil, spread, confectionery, chewing gum, and chocolate spread production.

Glossary

agar	polysaccharide (mixture of agaropectin and agarose) found in red algae
alginates	polysaccharides, including alginic acid, sodium, potassium, ammonium, calcium, and propylene glycol (food additives E400-E405), found in the cell wall of certain brown algae and possessing gelling properties
amylase	enzyme catalysing the breakdown of starch into sugars
carotenoids	terpenoid pigments, including carotenes and xanthophylls, produced by plants, algae, and certain microorganisms, and generally possessing antioxydant properties
carrageenan (E407)	generic name for a complex family of water-soluble sulfated polysaccharides found in a wide range of red algae (classified into kappa-, iota-, and lambda carrageenan, based on their chemical composition and structure)
dietary fiber	indigestible part of plant material; soluble fibers, which dissolve in water, are fermented in the colon to form gas and physiologically active metabolites, while insoluble fibers can be fermented in the colon or in the large intestine or remain metabolically inert
enzyme cofactor	chemical compound that binds to an enzyme and is required for the latter's biological activity
Floridean starch	amylopectin-like glucan isolated from red algae
fucoidan	algal polysaccharide composed primarily of sulphated L-fucose
furcellaran (E408)	highly sulphated polysaccharide composed primarily of D-galactose and with structural and and biological properties similar to the ones of kappa-carrageenan; also called *Danish agar*
galactan	polysaccharide of galactose monomers
glucan	polysaccharide of D-glucose monomers linked by

	glycosidic bonds
hyaluronidase	enzyme involved in the degradation of the glucosaminoglycan hyaluronic acid widely distributed throughout connective, epithelial, and neural tissues
laminarin	linear glucan found in the fronds of brown algae
microalga	microscopic, usually unicellular microalgae found ubiquitously in the water column down to a depth of 200 m, including diatoms, dinoflagellates, cyanobacteria, and microscopic green and red algae
phlorotannin	tannin (polyphenolic compound) found in brown algae
phycobilin	light-capturing pigment found in cyanobacteria and in red alagae, including the phycobiliproteins phycoerythrin (red) and phycocyanin (blue)
phycocolloid	hydrophilic polysaccharide (including alginates, carrageenans, agars, fucanes, laminarans, ulvans, and Floridean starch) found in algae, and forming gels in water by microscopic dispersion throughout the liquid solution
porphyran	galactan resembling agar
prebiotic	non-digestible food ingredient that stimulates the growth and/or activity of health-beneficial bacteria in the digestive system
PUFA	fatty acid containing more than one double bond in its backbone; omega-3 PUFAs (i.e. EPA and DHA) have a C=C double bond starting after the third carbon atom from the methyl end of the carbon chain – they are commonly found in marine and plant oils; like omega-3 PUFAs, omega-6 PUFAs (which are found in vegetable oils and have a C=C double bond starting after the sixth carbon atom from the methyl end of the carbon chain, are essential fatty acids, but excessive omega-6 PUFA uptake or a high omega-6-to-omega-3 PUFA ratio has negative health effects due to the resulting production of inflammatory n-6 eicosanoids
seaweed (macroalga)	macroscopic, multicellular, benthic marine alga (including macroscopic red, brown, and green algae)
sucrase	enzyme catalysing the hydrolysis of sucrose to fructose and glucose
taurine	organic acid widely distributed in animal tissue, especially in the large intestine; anti-oxidant, essential for cardiovascular functioning, and involved in

	osmoregulation, membrane stabilization, calcium signalling, and conjugation of bile acid
thermogenin	protein found in the mitochondria of brown adipose tissue cells and used to generate body heat by non-shivering thermogenesis
ulvan	sulphated polysaccharide found in green algae and composed of rhamnose, xylose, glucose, uronic acid, glucuronic acid, and iduronic acid as main constituents; ulvans are the only known plant source of the potent anti-coagulant iduronic acid; ulvans play key roles in collagen synthesis and the formation of cartilage

Abbreviations

BHT	tert-butyl-4-hydroxytoluene
DHA	docosahexaeonic acid
D.W.	dry weight
EPA	eicosapentaenoic acid
HPV	human *Papilloma* virus
PUFA	polyunsaturated fatty acid

Useful websites:

- www.adebiotech.org French network sharing information in the fields of biotechnology, food industry, health, energy and the environment; author of “Le livre turquoise” focusing on the applications of seafood.
- www.algaebase.org Information about seaweed: taxonomy, biology, and applications.
- www.algaeindustrymagazine.com Algae in Industry Magazine (A.I.M.): online trade publication addressing the growth and development of the algae biofuels and co-products industry.
- www.algasud.fr French network for the development of the exploitation of macro- and microalgae; author of “Le livre turquoise”, a free reference manual on the present and future development of the seaweed industry (in French)
- www.aquamin.org Information on Aquamin (Marigot Ltd.): seaweed-derived mineral supplement for knee osteoarthritis.
- www.ardtoemarine.co.uk Macro- and micro-algae cultivation in Ardtoe (Argyll, Scotland).
- www.bim.ie Website of Bord Iascaigh Mhara (Irish Sea Fisheries Board), includes the presentation of business plans for seaweed hatchery and grow-out farms, the description of seaweed cultivation methods, and an economical analysis of the industry.
- www.ceva.fr Centre d’Etude et de Valorisation des Algues (CEVA,

France): centre for algal research providing service in seaweed nutrient composition analysis, aquaculture project feasibility studies, and market analysis.

- www.cybercolloids.net Ireland-based global contract research to business development company in the area of food texture and nutrition with a specific knowledge in hydrocolloids.
- www.fao.org Food and Agriculture Organisation of the United States: free resources on the indusrial applications of seaweed.
- www.fmcbiopolymer.com FMC BioPolmer: Commercial producer of carrageenan, alginates/PGA, and other gums, as well as natural colourings *incl*. chlorophyll from algae. FMC also develops a range of products bakery, beverage, confectionary, dairy, and meat products containing these raw products, and it has recently commercialized Protasea, a fucoidan-based food supplement aimed at improving joint flexibility and lubrication, at stimulating the immune system, and at regulating cholesterol levels.
- www.foodhealthinnovation.com FHIC (Food & Health Innovation Service): Service offering support to Scottish food and drink companies seeking to exploit the burgeoning market for healthy food and drink products.
- www.hebrideanseaweed.co.uk Hebridean Seaweed Company: Company producing organic *Ascophyllum* meal that can be purchased in bulk (2kg to 1T) for use in the food or cosmetics industry.
- www.ifremer.fr French Research Institute for Exploitation of the Sea: Presentation of results from research studies on coastal environment management, marine living resource management, and marine technologies.
- www.innovactiv.com Innovactiv: Canadian company producing seaweed-based nutraceuticals (InSea™ and Peptibal™) and cosmetics.
- www.irishseaweed.com Irish Seaweed Research Group (*formerly known as the Irish Seaweed Centre*) at the National University Ireland in Galway, Ireland : Presentation of biological and nutraceutical information on algae.
- www.justseaweed.com Just eat Seaweed: Isle of Bute based seaweed foraging company selling fresh, dried, and crushed (condiment) “sea vegetables” worldwide, with products used by several UK celebrity chefs.
- www.lesalguesgastronomes.fr Les algues gastronomes: List of fresh, condiments, flakes, deli pastes, sushi sheets,… available to the general public on the French market, and a list of seaweed-based recipes (available in French and in English)
- www.maraseaweed.com Mara Artisanal Seaweed Harvested from Celtic Waters, and The Sea Spice Company: Artisanal seaweed products harvested in Scotland and Ireland.
- www.marinalg.org Marinalg: International resource on seaweed-derived hydrocolloids
- www.marlin.ac.uk Marine Life Information Network (MarLIN): information about marine organisms and their distribution around the

world.

- www.netalgae.eu Netalgae: Inter-regional network aimed at promoting sustainable development in the marine algal industry.
- www.nutraceuticalsworld.com: Nutraceuticals World: Monthly publications covering market and technology development in the dietary supplements, functional foods, and nutritional beverages industry.
- www.nutramara.ie NutraMara: Initiative by the Marine Institute (Ireland) to identify novel marine food ingredients.
- www.nutrition.org.uk British Nutrition Foundation: website with fact sheets, news, etc. about nutrition.
- www.polemerpaca.com PACA: Marine cluster supporting the Green Stars Project aimed at developing the industrial exploitation of microalgae through the establishment of an Institute for Excellence in Carbon-free Energy (IEED).
- www.ryandrum.com "Island Herbs" website by Dr. Ryan Drum: collection of information about algae and their medicinal applications.
- www.scotlandfoodanddrink.org Scotland Food and Drink: Service aimed at promoting the growth of the Sottish food and drink industry.
- www.seaweed.ie The Seaweed website: General information about marine algae.
- www.seaweedhealthfoundation.org.uk The Seaweed Health Foundation: Independent, non-profitable organization launched in 2010 by *Seagreens*. Service aimed at increasing awareness and understanding of seaweed quality for human food, health, and body care. This website provides a list of academic research partners, seaweed harvesters, processors, nutritionists, manufacturers, distributors, retailers and consumers with a special interest in sea vegetables. The foundation also offers food preparation and nutritional advice and market insight for new algal products.
- www.seaweedproducts.co.uk Seaweed Products: Organic production of edible seaweed, animal feed, and plant feed in the Shetland Islands.
- www.setalg.com Setalg: French company producing nutraceuticals from seaweed and from other seafood.
- www.submariner-project.eu Submariner: Website on sustainable uses of marine resources from the Baltic Sea.
- www.sushitrade.co.uk Sushitrade: Website with information on the development of the sushi industry in the U.K.

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