Importance of Seaweed

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Human Food

Seaweed as a staple item of diet has been used in Japan and China for a very long time. In 600 BC, Sze Teu wrote in China, "Some algae are a delicacy fit for the most honoured guests, even for the King himself." Some 21 species are used in everyday cookery in Japan, six of them since the 8th century. Seaweed accounts for some 10% of the Japanese diet and seaweed consumption reached an average of 3.5 kg per household in 1973, a 20% increase in 10 years (Indergaard 1983). Most important are Nori (Porphyra species), Kombu (Laminaria spp.), and Wakame (Undaria spp.). In the west, seaweed is largely regarded as a health food and, although there has been an upsurge of interest in seaweed as food in the last 20 years, it is unlikely that seaweed consumption there will ever be more than a fraction of the Japanese.

Regulations for the gathering of Palmaria palmata (dulse, dillisk), a red seaweed, are mentioned in the Icelandic sagas of the 10th century. This edible seaweed has been used also in Ireland and Scotland for a very long time. Chondrus crispus (Irish Moss) was recommended as a health remedy in Ireland at the beginning of the 19th century (Mitchell & Guiry 1983), but its use would appear to be unknown before this. Various red algae have been used in the Mediterranean as sources of dying agents and as anthelmintic and other health remedies since pre-Christian times (Stein & Borden 1984).

The use of kelps ("kombu" in Japan; "haidai" in China) dates back to at least the 5th century in China (Tseng 1980, 1982). The main species used is Laminaria japonica (Laminariales), but 8-11 other species are used also, mainly in Japan. Plants are dried after harvesting and either cut into strips or powdered. In Japan, kombu is used in the preparation of fish, meat dishes, soups and also as a vegetable with rice. Powdered kombu is employed either in sauces and soups or is added to rice in the same way as curry. Some kinds are used in making an infusion similar to tea. In 1976, about 176,000 wet tonnes of Laminaria spp. were collected from wild sources in Japan and about 22,000 t were cultivated. Laminaria is cultivated either by seeding blasted areas of rocky shores or by seeding ropes. In China, Laminaria japonica was imported from Japan from the 5th century until the founding of the People's Republic. In the early 1950s, the Chinese started to cultivate this species, which had been accidentally introduced from Japan to Dalian on the Yellow Sea.

Another kelp, Undaria pinnatifida (Laminariales), is widely used in Japan (where it is known as "wakame") and China ("qundai-cai") as food. In Japan this species is a more important crop than Laminaria both in value and production (Tseng 1982). Natural production increases were achieved for many years by placing stones on the sea bottom and blasting rocky reefs to increase the area suitable for attachment. Artificial seeding is carried out on cleared areas using either zoospore suspensions or sporophylls (specialised leaflets which bear the zoosporangia). Annual production from natural habitats in 1960-69 was 40 - 60,000 wet tonnes. Rope cultivation has been carried out since 1955 and the ropes are seeded by attaching sporophylls. Hybrids with superior growth and nutritional characteristics have been developed in Japan. In 1976, about 20,000 wet t were collected from wild sources and 127,000 wet t were cultivated. The harvested algae are dried after washing in freshwater. After resoaking the plant material is used as an additive to soups (wakame soup is served with virtually every meal in Japan); toasted (Yaki-wakame); used half resoaked, with boiled rice; and coated in sugar and tinned (Ito-wakame).

In China, Undaria pinnatifida was collected from natural habitats for centuries, mainly on the East China Sea coast. Plants are grown now on ropes in the Quingdao and Dalian areas (Yellow Sea), to where the algae were transplanted from Korea and, perhaps, Japan (Tseng 1982). Undaria is not as popular as Laminaria in China as a foodstuff and the growers find the plants difficult to manage. The annual production in China is, therefore, very low, amounting to no more than a few hundred tonnes in dry weight each year.

Nori is a red alga, Porphyra spp. (Bangiophyceae). Since the 17th century Japanese fishermen have planted either bamboo or brushwood ("hibi") in shallow waters to increase the substratum for nori. The hibi were placed in rocky areas in the autumn where the Porphyra spores settled and were then moved to sandy areas for the growth of the leafy plants in the winter. The discovery, in 1949, of the filamentous Conchocelis-phase in the life history of Porphyra by the British phycologist, K. M. Drew-Baker, led to the seeding of ropes from artificially-cultivated Conchocelis-phases. In 1977, some 300,000 t wet weight of Porphyra spp. were harvested in Japan and the production volume increased by 25% per annum in the 1970s. Nori is sold in sheets that may be toasted to give a green colour and then flaked and added to sauces, soups and broths. Sometimes it is just soaked and eaten. Small, dry nori sheets are used to wrap cold rice balls, which make a popular lunch-time snack for Japanese children. The food value of nori lies in its high protein content (25-35% of dry weight), vitamins and mineral salts, especially iodine. Its vitamin C content is about 1.5 times that of oranges and 75% of the protein and carbohydrates are digestible by humans, which is very high for seaweeds.

About 200 wet t of Porphyra were harvested off the coast of Wales until recently when fears of industrial pollution, particularly from nuclear plants, caused a shart reduction in the harvest. It is still used to make "laver-bread". This requires the Porphyra plants to be fried in either fat or oil, probably considerably reducing the vitamin content and food value. No artificial cultivation of Porphyra is carried out in this area.

Alginates

Alginates are cell-wall constituents of brown algae (Phaeophycota). They are chain-forming heteropolysaccharides made up of blocks of mannuronic acid and guluronic acid. Composition of the blocks depends on the species being used for extraction and the part of the thallus from which extraction is made. Extraction procedures probably also affect alginate quality. Alginates of one kind or another seem to be present in most species of brown algae but they occur in exploitable quantities (30-45% dry weight) only in the larger kelps and wracks (Laminariales and Fucales). Not all large brown algae have sufficiently large quantities of alginates to merit exploitation, for example, *Sargassum muticum*, an adventive species from Japan that has recently arrived in the Atlantic and Mediterranean, has, when dry, only 16-18% alginates.

The ammonia and alkali metal salts of alginic acid readily dissolve in cold water at low concentrations to give viscous solutions. Alginates, especially sodium alginate, are widely used in the textile industry because they form an excellent dressing and polishing material. Calcium alginate, which is insoluble in water, has been used in the manufacture of a medical dressing very suitable for burns and extensive wounds where a normal dressing would be extremely difficult to remove; the calcium alginate is extruded to make a fibre which is then woven into a gauze-like product; alginates with a high proportion of guluronic acid blocks are most suitable for this purpose. When applied to either a wound or burn, a network is formed around which a healthy scab may form; the bandage may be removed with a sodium chloride solution, which renders the alginate soluble in water. Previously, the physical removal of dressings caused considerable pain and disruption to wounds. Alginates are also used as a thickening paste for colours in printing textiles, as a hardener and thickener for joining threads in weaving; the alginates may subsequently be dissolved away, giving special effects to the material. Other uses include glazing and sizing paper, special printers' inks, paints, cosmetics, insecticides, and pharmaceutical preparations. In the USA alginates are frequently used as stabilisers in ice cream, giving a smooth texture and body, and also as a suspending agent in milk shakes. Alginates take up atomically heavy metals in a series of affinities; for example, lead and other heavy metals will be taken up in preference to sodium, potassium and other "lighter" metals; accordingly, alginates are useful in lead and strontium-90 poisoning.

About 25,000 t of alginic acid per annum are extracted world-wide. The main producers are Scotland, Norway, China and the USA, with smaller amounts being produced in Canada, Japan, Chile, France and Spain. In the USA, the giant kelp, *Macrocystis pyrifera* is used; it is harvested from large offshore beds off the coasts of California and Mexico. Some 120,000 t wet weight are gathered each year using ships equipped with cutting machinery. *Macrocystis* has the distinction of being the largest seaweed in the world; the largest attached plant recorded was 65 m long and the plants are capable of growing at up to 50 cm per day.

Ascophyllum nodosum and *Laminaria hyperborea* are used in Norway and Scotland. In 1979, some 65,000 wet t of *Ascophyllum* were harvested in Ireland, but a decrease in the demand for alginates in the early 1980s progressively reduced the harvest to about 32,000 t in 1995. About 12,000 t of alginates are produced in Scotland, but the amount of weed used is not known. Norway processes about 8,000 dry weight t of

Ascophyllum and 15,000 dry weight t of *Laminaria*, manufacturing about 10,000 t of alginates. Canada uses about 7,000 t of *Ascophyllum* and *Laminaria*, producing about 1,200 t of alginates. Japan produces about 1,400 t of alginates from about 33,000 t of weed, mainly Laminariales. China, a relatively recent addition to the alginate manufacturers of the world, produced about 10,000 t of alginates in 1994 from cultivated *Laminaria japonica* . Recent studies suggest that China now has 50% of the European market for alginates and may have a similar percentage of the north American market.

Agars

Agar, a general name for polysaccharides extracted from certain kinds of red algae, is built up of alternating D- and L- galactopyranose units. The name agar is derived from a Malaysian word "agar-agar", which literally means "seaweed". As the gelling agent "kanten", it is known from Japan since the 17th century; extracts from red seaweeds were carried up the mountains to freeze overnight so that water and other impurities could be extracted from the material. Agar finds its widest use as a solid microbiological culture substrate. Modern agar is a purified form consisting largely of the neutral fraction known as agarose; the non-ionic nature of the latter makes it more suitable for a range of laboratory applications. Agar in a crude or purified form also finds wide usage in the food industry where it is used in various kinds of ices, canned foods and bakery products.
The best quality agar is extracted from species of the red algal genera *Pterocladia* and *Gelidium*, which are harvested by hand from natural populations in Spain, Portugal, Morocco, the Azores, California, Mexico, New Zealand, South Africa, India, Chile, and Japan. Agars of lesser quality are extracted from *Gracilaria* and *Hypnea* species. Agar quality is seasonal in *Pterocladia* species, being low in the colder months and high in the warmer. At present, there is no commercial mariculture of agar-producing weeds carried out in the world, largely because techniques for growing weeds with good-quality agar have not been developed. About 10,000 t of agar are produced world-wide at present. There is currently a shortage of exploitable populations of agar-producing seaweeds and agar is consequently an expensive product. At present, more than 50% of all agar being produced is food-grade agar being produced from *Gracilaria.*

Carrageenans

Carrageenan is a general name for polysaccharides extracted from certain kinds of algae which are built up, in contrast to agar, from D-galactopyranose units only. The word carrageenan is derived from the colloquial Irish name for this seaweed, carrageen (from the Irish placename, probably Carrigeen Head in Co. Donegal, *Carraigín*; "little rock") the use of this seaweed to extract a gel is known in Ireland since 1810. *Chondrus crispus* used to be the sole source of carrageenan, but species of *Gymnogongrus, Eucheuma, Ahnfeltia* and *Gigartina* are now commonly used. About 25,000 t of carrageenan are manufactured world-wide, and although *Chondrus* is no longer the unique source, it is still the principal one. Modern carrageenan is a branded product designed, by mixing various types of carrageenan, to give a gel with particular qualities. Most of the Chondrus that is used in the carrageenan industry comes from the Maritime Provinces of Canada (Nova Scotia etc.), where about 50,000 wet t of *C. crispus* are harvested each year from natural populations. The bulk of the harvest is collected using long-handled rakes and dredges from small boats. The seaweed is then dried, either by spreading and air-drying or by using rotary dryers, and exported to the USA and Denmark for processing.

Uses of Seaweeds

Seaweeds are used in many maritime countries as a source of food, for industrial applications and as a fertiliser. The major utilisation of these plants as food is in Asia, where seaweed cultivation has become a major industry.

In most western countries food and animal consumption is restricted and there has not been any pressure to develop seaweed cultivation techniques. This present and potential uses of seaweeds. Industrial utilisation is at present largely confined to extraction for phycocolloids and, to a much lesser extent, certain fine biochemicals. Fermentation and pyrolysis are not been carried out on an industrial scale at present but are possible options for the 21st century.
The present uses of seaweeds at present are as human foods, fertilisers, and for the extraction of industrial gums and chemicals. They have the potential to be used as a source of long- and short-chain chemicals with medicinal and industrial uses. Marine algae may also be used as energy-collectors and potentially useful substances may be extracted by fermentation and pyrolysis.

Medicinal Uses

Many claims have been made for the effectiveness of seaweeds on human health. It has been suggested, amongst other things, that seaweeds have curative powers for tuberculosis, arthritis, colds and influenza, worm infestations, and may even improve one's attractiveness to the opposite sex.
Digenea (Ceramiales; Rhodophycota) produces an effective vermifuge (kainic acid). *Laminaria* and *Sargassum* species have been used in China for the treatment of cancer. Inhibition of cancerous tumours in animals seems to be caused by long-chained polysaccharides. Dry *Laminaria* stipes have long been used in obstetrics to dilate the cervix and were known as "*Laminaria* tents" (Stein & Borden, 1984); the dry stipe slowly takes up water and expands; such stipes are used in China for the insertion of intrauterine devices. Aqueous extracts from two red algae belonging to the Dumontiaceae have been found to inhibit the *herpes simplex* virus but no tests have been carried out on humans. Another red alga (*Ptilota*) produces a protein (a lectin) which preferentially agglutinates human B-type erythrocytes *in vitro*. Extracts of *Ptilota* are being marketed. Many of the reported medicinal effects of marine algae have not been substantiated.

What are Harmful Algal Blooms (HABs)?

Harmful algae are microscopic,single-celled plants that live in the sea. Most species of algae or phytoplankton are not harmful and serve as the energy producers at the base of the food web, without which higher life on this planet would not exist.
Occasionally, the algae grow very fast or "bloom" and accumulate into dense, visible patches near the surface of the water. "Red Tide" is a common name for such a phenomenon where certain phytoplankton species contain reddish pigments and "bloom" such that the water appears to be colored red. The term "red tide" is thus a misnomer because they are not associated with tides; they are usually not harmful; and those species that are harmful may never reach the densities required to discolor the water.
Unfortunately, a small number of species produce potent neurotoxins that can be transfered through the food web where they affect and even kill the higher forms of life such as zooplankton, shellfish, fish, birds, marine mammals, and even humans that feed either directly or indirectly on them.
Scientists now prefer the term, HAB, to refer to bloom phenomenon that contain toxins or that cause negative impacts.

Human Illness Associated with Harmful Algae

Man is exposed principally to the naturally-occurring toxins produced by harmful algae through the consumption of contaminated seafood products. The most significant public health problems caused by harmful algae are:

Amnesic Shellfish Poisoning (ASP)
Ciguatera Fish Poisoning (CFP)
Diarrhetic Shellfish Poisoning (DSP)

Neurotoxic Shellfish Poisoning (NSP)
Paralytic Shellfish Poisoning (PSP)
Each of these syndromes are caused by different species of toxic algae which occur in various coastal waters of the US and the world. With the increase in interstate and international transport of seafood, as well as international travel by seafood consumers, there are virtually no human populations that are free of risk. Since 1978, illnesses in the US due to natural algal toxins have included PSP, NSP, CFP, and ASP. No incidents of DSP have yet been verified in this country. Although records are incomplete because reporting to the Centers for Disease Control (CDC) is voluntary, evidence indicates that ciguatera was responsible for about half of all seafood intoxications. A growing body of evidence indicates that incidents of ASP are on the increase and that DSP may shortly make its debut in the United States, since the causative organisms occur throughout the temperate coastal waters of the US.

Amnesic Shellfish Poisoning (ASP)

causative organisms: *Pseudo-nitzschia* sp.
toxin produced: Domoic Acid

ASP can be a life-threatening syndrome. It is characterized by both gastrointestinal and neurological disorders (Bates et al., 1989). Gastroenteritis usually develops within 24 hours of the consumption of toxic shellfish; symptoms include nausea, vomiting, abdominal cramps, and diarrhea. In severe cases, neurological symptoms also appear, usually within 48 hours of toxic shellfish consumption. These symptoms include dizziness, headache, seizures, disorientation, short-term memory loss, respiratory difficulty, and coma. In 1987, four victims died after consuming toxic mussels from Prince Edward Island, Canada. Since that time, Canadian authorities have monitored both the water column for the presence of the causative diatom, and shellfish for the presence of the toxin, domoic acid. Shellfish beds are closed to harvesting when the domoic acid concentration reaches 20 μg/g shellfish meat. Fish and crab viscera can also contain domoic acid, so the risk to human consumers and animals in the marine food chain is more significant than previously believed.

Ciguatera Fish Poisoning (CFP)

causative organisms: *Gambierdiscus toxicus*, *Prorocentrum* spp., *Ostreopsis* spp., *Coolia monotis*, *Thecadinium* sp. and *Amphidinium carterae*
toxins produced: Ciguatoxin/Maitotoxin

CFP produces gastrointestinal, neurological, and cardiovascular symptoms. Generally, diarrhea, vomiting, and abdominal pain occur initially, followed by neurological dysfunction including reversal of temperature sensation, muscular aches, dizziness, anxiety, sweating, and a numbness and tingling of the mouth and digits. Paralysis and death have been documented, but symptoms are usually less severe although debilitating (Miller, 1991). Recovery time is variable, and may take weeks, months, or years. Rapid treatment (within 24 hours) with manitol is reported to relieve some symptoms. There is no antidote, supportive therapy is the rule, and survivors recover. Absolute prevention of intoxication depends upon complete abstinence from eating any tropical reef fish, since there is currently no easy way to measure routinely ciguatoxin or maitotoxin in any seafood product prior to consumption.

Diarrhetic Shellfish Poisoning (DSP)

causative organisms: *Dinophysis* sp.
toxin produced: Okadaic Acid

DSP produces gastrointestinal symptoms, usually beginning within 30 min to a few hours after consumption of toxic shellfish (Yasumoto and Murato, 1990). The illness, which is not fatal, is characterized by incapacitating diarrhea, nausea, vomiting, abdominal cramps, and chills. Recovery occurs within three days, with or without medical treatment.

Neurotoxic Shellfish Poisoning (NSP)

causative organism: ***Gymnodinium breve***
toxins produced: Brevetoxins

NSP produces an intoxication syndrome nearly identical to that of ciguatera. In this case, gastrointestinal and neurological symptoms predominate. In addition, formation of toxic aerosols by wave action can produce respiratory asthma-like symptoms. No deaths have been reported and the syndrome is less severe than ciguatera, but nevertheless debilitating. Unlike ciguatera, recovery is generally complete in a few days. Monitoring programs (based on G breve cell counts) generally suffice for preventing human intoxication, except when officials are caught off-guard in previously unaffected areas.

Paralytic Shellfish Poisoning (PSP)

causative organisms: ***Alexandrium*** **spp.,*Gymnodinium catenatum, Pyrodinium bahamense***
toxins produced: Saxitoxins

PSP, like ASP, is a life threatening syndrome. Symptoms are purely neurological and their onset is rapid. Duration of effects is a few days in non-lethal cases. Symptoms include tingling, numbness, and burning of the perioral region, ataxia, giddiness, drowsiness, fever, rash, and staggering. The most severe cases result in respiratory arrest within 24 hours of consumption of the toxic shellfish. If the patient is not breathing or if a pulse is not detected, artificial respiration and CPR may be needed as first aid. There is no antidote, supportive therapy is the rule and survivors recover fully. PSP is prevented by large-scale proactive monitoring programs (assessing toxin levels in mussels, oysters, scallops, clams) and rapid closures to harvest of suspect or demonstrated toxic areas.

Algae

V. Algae Uses

Human ingenuity has found many uses for algae. Algae provide food for people and livestock, serve as thickening agents in ice cream and shampoo, and are used as drugs to ward off diseases. More than 150 species of algae are commercially important food sources, and over $2 billion of seaweed is consumed each year by humans, mostly in Japan, China, and Korea. The red alga *Porphyra*, called nori, is the most popular food product. After harvesting, nori is dried, pressed into sheets, and used in soups, sauces, sushi, and condiments. Algae are considered nutritious because of their high protein content and high concentrations of minerals, trace elements, and vitamins. The high iodine content of many edible algae may contribute to the low rates of goiter observed in countries where people frequently eat algae.

In coastal areas of North America and Europe, seaweeds are fed to farm animals as a food supplement. Cyanobacteria species that are high in protein, such as *Spirulina,* are grown commercially in ponds and used mostly as a health food and cattle dietary supplement. Seaweeds also are applied to soils as a fertilizer and soil conditioner, as their high concentrations of potassium and trace elements improve crop production. Some species of cyanobacteria can turn atmospheric nitrogen into ammonia, a form that can then be used by plants as a nutrient. Farmers in tropical countries grow cyanobacteria in their flooded rice paddies to provide more nitrogen to the rice, increasing productivity as much as tenfold.

Seaweeds are a critical source of three chemical extracts used extensively in the food, pharmaceutical, textile, and cosmetic industries. Brown algae yield alginic acid, which is used to stabilize emulsions and suspensions; it is found in products such as syrup, ice cream, and paint. Different species of red algae provide agar and carrageenan, which are used for the preparation of various gels used in scientific research. Bacteria, fungi, and cell cultures are commonly grown on agar gels. Agar is also used in the food industry to stabilize pie fillings and preserve canned meat and fish. Carrageenan is also used as a thickening and stabilizing agent in products such as puddings, syrups, and shampoos.

Algae have been used for centuries, especially in Asian countries, for their purported powers to cure or prevent illnesses as varied as cough, gout, gallstones, goiter, hypertension, and diarrhea. Recently, algae have been surveyed for anticancer compounds, with several cyanobacteria appearing to contain promising candidates. Diatoms also have been used in forensic medicine, as their presence in the lungs can indicate a person died due to drowning.

Algae can also serve as indicators of environmental problems in aquatic ecosystems. Because algae grow quickly and are sensitive to changing environmental conditions, they are often among the first organisms to respond to changes. For example, depletion of the diatom community in the Florida Everglades provided strong evidence of phosphorus-related changes in this unique ecosystem. Algal blooms may deplete oxygen concentrations in water and smother fish and plant life, as well as prevent light penetration for algae at lower depths, preventing photosynthesis.

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