17

Seaweeds

Vegetation of the sea is more primitive in the evolutionary scale than that of the land. Seaweeds vary tremendously in form and elaborateness of organization, ranging from one-celled, microscopic flagellates to giant kelp which grow to be five or six hundred feet long. They have no flowers or seeds, their reproduction and distribution being accomplished by asexual spores which are simpler structures than seeds. They do not have roots but are anchored to the substratum by a structure called a holdfast and absorb their necessary mineral nutrients directly from the sea water through their leaf-like fronds. Like land plants, they possess chlorophyl, by which they utilize the energy of sunlight to synthesize carbohydrates, proteins, and fats from water, carbon dioxide, and, as required, other inorganic chemicals. These products differ chemically from their analogues in land plants. Marine algae have some human nutritional value, but this is not their most interesting use. Some of the chemicals derived from them have peculiar properties which give them special values for industrial or medical purposes. It is these that put algae among the important resources of the sea. However, algae are not universally appreciated; there are great stands of them along some coasts which are almost or quite completely neglected. Even where they are harvested and manufactured into industrial products, they are not used up to their full potential value.

Scientists classify marine algae into four groups according to their principal pigments: green, blue, red, and brown. Only the red

and the brown have significant commercial value at present. Red algae range in variety from single-cells of microscopic size through filamentous, branching forms to broad-fronded plants one or two meters long. They are widely distributed, but are most abundant in temperate climates. In general, they occur in deeper water than brown algae, extending from the intertidal zone to depths of 130 meters. Brown algae are more elaborately organized than the red, with great variety of form and size, ranging from small, delicate, filamentous plants to the giant kelps of the Pacific. They, too, are widely distributed but are most abundant in temperate and cool seas.

It is possible by aerial photography to estimate the size of stands of buoyant species of brown algae, thanks to the fact that the plants have fronds which float at the surface and so are always visible. The smaller algae which are exposed only at extremely low tides, if at all, present a more difficult problem. They must be assessed by a combination of processes, including aerial photography, sampling by mechanical grab instruments, and underwater surveying by divers.

The few thorough surveys that have been made show that in any given region, the distribution and density of the marine algae vary according to the geological character of the substrata. Also, the amount of plant material present varies seasonally and from year to year. For example, the standing crop of giant kelp growing in the vicinity of La Jolla, California, varies between 25 and 40 tons (wet weight) per acre. The annual yield, by growth, runs about 4 to 6 tons per acre.[1]

In three widely separated areas surveyed off the coast of Scotland, the total estimated quantity of kelp fluctuated, over the course of several years, between 7.8 and 18.1 tons per acre.[2] In the western part of the Sargasso Sea the quantity of *Sargassum* was found to vary in three years of observation between about 2 and somewhat more than 5 tons, wet weight, per square nautical mile. Assuming these figures to be representative of the whole area, there would be 4 to 10 million tons of pelagic vegetation in the entire Sargasso Sea.[3] Unfortunately this plant is probably not dense enough any place for profitable commercial exploitation. Again, in the Digby Neck area of Nova Scotia, where it was estimated that 80,000 tons of rockweed (*Ascophyllum* and *Fucus*) were growing on 2,500 acres, the density varied from 8 to 57 tons per acre.[4] Thus, variations in the supply is a problem with which anyone exploiting seaweed resources must contend, and the understanding of the causation of these

variations must be one of the principal goals of seaweed research.

The principal commercial products of red algae are agar and carrageenin. These consist of 13.2 to 20.8 per cent of moisture, 1.1 to 2.5 per cent of protein, 60.3 to 79.7 per cent of carbohydrates, and 3.5 to 16.6 per cent of ash.[5] In spite of occasional extravagant claims to the contrary, the carbohydrates in these products are not of great value as a source of energy because human enzymes are unable to digest much of them. Researchers have estimated the coefficient of digestibility of carrageenin to run about 33 per cent in dogs, 6 per cent in man, 50 per cent in laboratory rats; that of agar is about 28 per cent in rats. There is some evidence to suggest that agar may act as a nutritional aid when mixed in proper proportions with other feeds.

People in many parts of the world eat red algae in a great variety of forms—fresh in salads, dried, pressed into rolls for chewing like gum, boiled as a vegetable, mixed with meal and made into cakes, boiled with milk for pudding, as the base of a condiment for rice, as a cheap substitute for birds' nests for thickening soups, and as a thickener for puddings. In China the derivative of red algae, agar, is cut into small pieces and treated with soy sauce, vinegar, and red pepper and eaten as a condiment. In Japan, agar jelly is used in making bean cakes. In America agar is added to some breakfast foods to furnish roughage. Moreover, its low nutrient value makes it a useful ingredient of low-calorie bakery products prepared for reducing diets.

Agar is peculiarly useful for making jellies in tropical countries because it sets quickly, has eight to ten times more gelatinating power than gelatin and therefore does not require refrigeration to form a firm jelly, even in the hottest weather. It has other advantages over gelatin for it is acceptable to religious groups that eschew substances originating from the hooves of animals. It does not require sugar to form a jelly as does pectin, and it keeps well because it is not attacked by most putrefying bacteria. This last is a very important property which is probably not nearly utilized fully, for it gives agar value as a temporary preservative. In hot places where refrigeration facilities are lacking, foods like meat and fish, which ordinarily spoil quickly, are sometimes cooked with agar. Thus, by being embedded in a gel which resists bacteria, these foods can remain wholesome for a longer time than foods not so protected.[6]

In Japan a small brown alga called matsumo (*Heterochordaria abietina*) is used for preserving mushrooms. The mushrooms are

soaked first in salt water and then packed in barrels in layers alternating with layers of salted matsumo.

The organic composition of brown algae, as of red algae, varies from one species to another. For any one species it varies geographically, and according to depth, and even from one part of a plant to another. It is hardly surprising therefore that published analyses vary. The percentage composition of the dried product as determined in northern Europe, Nova Scotia, Russia, and Japan falls within the following limits:

Carbohydrates	
Mannitol	3 — 27
Alginic acid	11 — 33
Laminarin	0 — 36
Fucoidin	2 — 11
Cellulose	1 — 10
Proteins	3 — 16
Oils, fats, waxes	1.8 — 3.6
Ash	14 — 46

Brown algae are of negligible importance as human food in the Western World. During hard times coastal Europeans have eaten them, and before the days of highly developed transportation of fresh vegetables and fruits they ate them often, but that was more than a hundred years ago. However, in parts of the Orient, chiefly in Japan, China, Indonesia, the Philippines, and in Oceania, brown algae are highly appreciated. In Japan alone, 310,000 tons of brown, red, and green algae were harvested in 1955. The plants are sometimes eaten simply as vegetables, raw or cooked. But mostly they are dried and manufactured into products that are variously used, such as for flavoring sauces on fish and rice, for thickening soups, or for making into savory wafers, cakes, or other confections.[7] At the end of the last war, occupation officials found how important algae are to the Japanese when they tried to get the people to use *Laminaria* (a genus of brown alga) less for food and more for producing potash, which was badly needed then. The Japanese fishery and prefectural officials resisted these efforts. They were quite willing to agree that seaweed might have little nutritional value, but they argued that depriving the people of these sea vegetables to which they had been so long accustomed would have a bad psychological effect. In any case, all food was scarce at that time, so that they needed whatever nourishment the algae afforded, little though it might be.[8]

A few blue-green algae (Cyanophyceae) and green algae (Chlorophyceae), among them sea lettuce (*Ulva*), are eaten in various places, particularly the Orient and Oceania, as vegetables, as gar-

nishes, or for flavoring. The composition of sea lettuce has been assayed as follows: water, 13 to 19 per cent; crude protein, 12 to 19 per cent; and carbohydrates 46 to 53 per cent. Japanese scientists have demonstrated the proteins of these algae to have less nutritive value than those of an edible red alga, *Porphyra.*[9] The nutritive value of the carbohydrates of blue-green and green agae remains to be determined.

It has been suggested, though not demonstrated, that people who eat seaweeds from early childhood, like the Japanese, may acquire a specialized bacterial flora in their intestines which helps to digest these foods. To be sure, there are certain bacteria in the sea which live on algae, thriving on their complex carbohydrates. Perhaps like a number of marine microorganisms that have been artificially cultured in laboratories, they can survive relatively high temperatures. Therefore it is conceivable that they could be hardy enough to flourish in the human alimentary tract once they were introduced to that environment. Thus some Oriental people might derive significantly more food value from seaweeds than people and animals not conditioned to such a diet. This suggests possibilities in artificially cultivating algae-digesting bacteria.

Even if all the carbohydrates and proteins in seaweeds were fully digestible, the harvestable quantities could not add significantly to the present production of those nutrients from other sources. In Japan, for example, where seaweeds are considered such an absolute necessity that there is no question of educating the public to eat them, the total annual production of fresh weed is less than 3 per cent of the rice harvest. When translated into nutrients, the quantity becomes negligible. Thus the value of marine algae to the food supply of a country is less likely to be in their carbohydrates and proteins than in their minerals and vitamins. Algae have an extraordinary capacity to extract mineral salts from sea water. Thus some brown algae of the genus *Laminaria* have been shown to contain 20,000 to 30,000 times more iodine per unit of volume than the surrounding sea water, 300 times more manganese, 200 times more copper, 500 times more phosphorus.

Any use of algae which requires a controlled product must take into account the variations in mineral composition. This is difficult because these variations are more or less erratic and sometimes are very great. The content of iron per kilogram of oven-dried samples of one species of *Pelvetia* taken at Plymouth, England, for example, was 195 milligrams in January 1949, 565 in May 1949, and 2,040 in June 1950.[10] Ranges of variation of other elements in the same samples (Table 17-1) are even greater.

TABLE 17-1. AMOUNT OF CERTAIN ELEMENTS IN OVEN-DRIED SAMPLES OF SEVERAL SPECIES OF ALGAE COLLECTED OFF PLYMOUTH, ENGLAND
(in milligrams per kilogram)

Element	Jan. 1949	May 1949	June 1950
Cobalt	0.35 — 1.46	0.25 — 1.39	0.22 — 2.00
Nickel	1.5 — 8.2	1.6 — 6.0	1.8 — 9.3
Molybdenum	0.15 — 0.69	0.10 — 0.65	0.16 — 1.32
Iron	168 — 717	138 — 638	320 — 3,380
Lead	4 — 26	2 — 12	4 — 16
Tin	0.7 — 1.2	0.5 — 1.8	0.2 — 2.2
Zinc	40 — 136	47 — 76	59 — 116
Vanadium	1.0 — 3.3	0.3 — 2.6	0.5 — 11.9
Titanium	9 — 20	2 — 38	4 — 308
Chromium	0.6 — 2.6	0.4 — 1.8	0.7 — 3.7
Silver	0.2 — 0.7	0.2 — 0.4	0.0 — 0.4
Rubidium	80 — 250	—	—
Lithium	4 — 8	—	—
Strontium	2,200 — 4,000	> 700	420 — 1,150
Barium	50 — 120	13 — 44	16 — 64
Manganese	30 — 800	9 — 155	30 — 121
Copper	4 — 20	< 3 — 14	5 — 31

SOURCE: Tabulated from data given by W. A. P. Black and R. L. Mitchell, "Trace Elements in the Common Brown Algae and in Sea Water," *Journal of the Marine Biological Association of the United Kingdom*, XXX:3 (1952), 575–84.

Biochemists have definitely established that carotene, the precursor to vitamin A, and vitamins B_1, B_2, B_{12}, C, D, and E occur in marine algae. Some Eskimos get about half of their vitamin C from marine algae, which they eat raw, or dipped in broth, hot water, or blubber oil.[11] Like everything about seaweeds, their known vitamin content varies geographically, seasonally, and with depth, as illustrated in Tables 17-2, 17-3, and 17-4. But nowhere has it been measured in a statistically useful way to establish quantitatively the normal seasonal ranges.

TABLE 17-2. VITAMIN C CONTENT IN SAMPLES OF SOME COMMON SEAWEEDS OF THE SAN JUAN ARCHIPELAGO
(milligrams per 100 grams fresh weight)

Brown algae	
From the surface, littoral and upper sublittoral zones. 6 species	4 — 53
Dredged from a depth of 5–10 fathoms. 4 species	1 — 2
Green algae	
From the surface and littoral zone. 2 species	15 — 46
Red algae	
From the surface, littoral and sublittoral zones. 8 species	1 — 60
Dredged from a depth of 5–10 fathoms. 7 species	less than 1

SOURCE: Earl R. Norris, Mary K. Simeon, and Hal B. Williams, "The Vitamin B and Vitamin C Content of Marine Algae," *Journal of Nutrition*, XIII:4 (1937), 425–33.

TABLE 17-3. VITAMIN C CONTENT IN SAMPLES OF SOME COMMON ALGAE OF NORTHERN EUROPE AND JAPAN
(milligrams per 100 grams fresh weight)

Month	9 species of brown algae, northern Europe	3 species of red algae, northern Europe	*Gracilaria confervoides* a red alga, Japan	Sea lettuce a green alga, northern Europe	Sea lettuce and *Enteromorpha* green algae, Japan
January	3 — 31	40 — 50	96 — 159	—	171 — 241
February	4 — 38	27 — 44	—	27	—
March	5 — 61	24 — 63	149	—	204 — 228
April	7 — 75	29 — 61	150	28	171 — 195
May	15 — 59	36 — 83	168	—	131 — 173
June	—	—	16	—	30 — 64
July	—	—	—	—	—
August	—	—	—	—	—
September	11 — 108	46	—	—	—
October	—	49	—	—	—
November	33 — 44	46	—	—	—
December	—	—	74	—	84 — 90

SOURCES: Gulbrand Lunde and John Lie, "Vitamin C in Meeresalgen," *Hoppe-Seyler's Zeitschrift für Physiologische Chemie,* CCLIV:3–6 (1938), 227–40; and Yasuhiko Tsuchiya, "Physiological Studies on the Vitamin C Content of Marine Algae," *Tohoku Journal of Agricultural Research,* I (1950), 97–102.

TABLE 17-4. VITAMIN B (B_1) CONTENT OF SOME MARINE ALGAE FROM THE SAN JUAN ARCHIPELAGO

Material Tested	Where Obtained	Shermen units of vitamin B (B_1) per gram of dried material
Brown algae		
Alaria valida	upper sub-littoral zone	2.5
Laminaria spp.	dredged from 5–10 fathoms	2.0
Red algae		
Porphyra nereocystis	surface	5.5
Porphyra perforata	littoral zone	5.0
Rhodymenia pertusa	dredged from 5–10 fathoms	2.2
Green algae		
Enteromorpha	littoral zone	trace
Ulva lactuca	surface	4.0
Dried brewer's yeast		13.3

SOURCE: Earl R. Norris, Mary K. Simeon, and Hal B. Williams, "The Vitamin B and Vitamin C Content of Marine Algae," *Journal of Nutrition,* XIII:4 (1937), 425–33.

There is considerable difference of opinion about the value of marine algae for stock feeds. Few controlled feeding experiments have been conducted which have taken into account seasonal cycles in nutritive value and variation among the different species of algae. Black has written the following on this subject.

In carrying out digestibility trials with seaweed, one of the main difficulties is the great variation in composition. This, however, is also a marked feature of farm foods, especially grassland products. The changes are typical of all plants and, just as in the case of grasses where the composition is closely related to the ratio of leaf to stem, in seaweeds the composition depends on the ratio of frond (leaf) to stipe (stalk).[12]

Animal feeding studies that have been made in a number of places point to the following general conclusions: Domestic animals can digest much of the carbohydrates of seaweeds. Indeed in Iceland and in the Orkney Islands, sheep live almost exclusively on seaweeds during most of the year. However, the results of such a diet are not good. For instance, on North Ronaldsay (one of the Orkneys) lives a herd of 2,000 or more black sheep which feed mostly on seaweed during a large part of the year. The animals are kept close to the shore by a wall that surrounds the entire island, and they are admitted to pasture only at lambing time or before slaughter. Accounts in literature, evidently copied one from another, glow with enthusiasm over the splendid animals nourished on this diet. On the other hand, people who have actually seen them say they are poor looking beasts and a most unfavorable testimonial to marine algae as animal feed.

It is clear from all experience that although seaweeds are not a satisfactory exclusive food for sheep, cows, horses, pigs, and poultry, they can be used in portions up to about 15 per cent of the normal ration as a supplementary food. In such quantities they are safe. Apart from the digestible carbohydrates, minerals, and vitamins which they provide, they may have a special beneficial effect in enhancing the nutritional value of the basic ration through their mechanical action on the alimentary tract.

They may also be useful in providing minerals, including trace elements, as well as vitamins. Whatever their nutritional value, it can be precisely determined only by systematic biochemical and feeding experiments planned to encompass adequately all the ranges of variation in the qualities of algae—variations from time to time, place to place, and species to species. Moreover, technological research is needed to devise cheap processes of converting the alginates to a more digestible form, of reducing the ash content, of improving the palatability, and of standardizing the product.

Meanwhile there are over a dozen factories which manufacture meal from brown seaweeds. These are located in the United States, Nova Scotia, Eire, Scotland, France, Denmark, the Netherlands, Norway, and South Africa. The product is usually marketed as dried kelp meal, or mixed with fish meal or stick-water con-

centrates. Perhaps the most elaborate processing is done in a Norwegian factory, which harvests the brown alga *Ascophyllum nodosum,* dries it in the sun, removes the excess salt, and caramelizes the sugar content to eliminate an odor repellent to cattle and horses. The meal made from this process is claimed to have a food value equal to that of oats and to prevent or cure mineral deficiency diseases. It is further claimed that when fed to animals at the rate of 2 to 3 grams per living kilogram of animal, per day, it results in "better milk, eggs, meat, and fur." [13]

In the maritime states of Europe and North America and in Oceania and the Orient, farmers living within convenient traveling distance of the shore gather seaweeds for use as manure. Because the weeds are bulky and watery, it takes 20 to 50 tons an acre to supply enough nitrogen, phosphoric acid, and potash to satisfy the requirements of farm crops. Therefore it is economical to use them only within 8 or 10 miles of shore and only when labor is plentiful and not too dear. The transportation cost can be reduced somewhat by allowing the plants to dry partially on the beach before carting them off, but if they are left too long to the weather, some of their nutrients, especially potash, will be lost.

In general, fresh seaweeds contain at least two-thirds as much nitrogen as average barnyard manure, about one-third to one-half as much phosphoric acid, and about twice as much potash. Its balance as a fertilizer can be improved by adding superphosphate. The trace element constituents must make seaweeds especially valuable for some deficient soils, but here again, for scientific use, seasonal, geographic and species differences in concentration must be taken into account, together with the particular needs of the soil to be treated.

It is not only their nutrients and minerals which give seaweeds manurial value, but their physicochemical action on soil as well.[14] In fact, soil conditioners may ultimately prove to be one of the most important seaweed products for agricultural use. The more soluble salts of alginic acid like sodium alginate seem to enter into firm chemical union with constituents of the particles of soil to which they have been added. Whatever the mechanism, the result is to increase the water-holding power, the stability of soil crumbs, and consequently the availability of oxygen to all organisms living in the soil—microscopic and macroscopic, animal and plant.

Another valuable potential use of seaweeds is as a source of antibiotics. When microscopic fresh water algae like *Chlorella* (of which there are closely related marine forms) are cultivated, the nutrient media in which they are grown must be renewed from time

to time. Otherwise, a substance which the plants synthesize limits their own growth. This antibiotic substance also can inhibit growth and metabolic activity of other microscopic algae as well as of some gram positive and gram negative pathogenic bacteria. This discovery was put to very good use during the last war. In several military camps in California and Nevada, open sewage settling pools were heavily inoculated with *Chlorella* and thereby made bacteriologically safe enough so that their effluents could be discharged into local streams without endangering public health. During the summer months, the coliform count was often actually lower in the nonchlorinated pools inoculated with *Chlorella* than in the merely chlorinated pools.

Scientists of the University of California [15] systematically examined Pacific coast marine algae for antibiotic activity. In the course of these researches they obtained from samples of many species of seaweeds extracts which inhibit growth of one or more of three species of bacteria grown in laboratory cultures. The conditions of the experiments rule out the likelihood that this antibiotic effect could be ascribed to iodine or to ocean-borne bacterophage or other contaminants of the algae.

The results of these and later studies show antibiotic activity to be present in the green alga sea lettuce and among several species of browns and reds. It varies in strength from one part of a plant to another, and from one species to another. The assortment of bacteria affected varies among species. It is neither present in all species nor evenly distributed throughout the body of any plant in which it occurs. For example, extracts from fronds are always more active than those from the stipes. It runs a seasonal cycle that parallels in a suggestive way the cycle of trace elements and of vitamins. The antibiotic substances seem to be absent during the winter, at which time the trace elements and vitamins are at their lowest ebb. At around the same time the concentrations of proteins and of alginic acid are highest. The significance of these relations remains a subject for future study.[16]

The antibiotic action of marine algae may explain the preservative value of agar, referred to above. Natives of some Pacific islands apparently use the same principle in wrapping fresh fish in the large fronds of certain seaweeds to delay putrefaction.

The twentieth-century wars have stimulated algal industries to emerge from a rather low level of technological development. Previously these industries had always been directed towards the extraction of only a few products like iodine, potash, soda, and agar, while other constituents of unknown or unappreciated value were

wasted. The process of extracting sodium carbonate from the ash of burned kelp originated in France in the seventeenth century. From this beginning an industry grew, spread, and flourished in northern Europe during the eighteenth century and part of the nineteenth and in Japan during the nineteenth and twentieth. With the discovery of other sources of soda, the kelp burning industry suffered a depression from which it was rescued by the development of a process for extracting iodine from seaweed and by an increase in the demand for potash.

For kelp burning, suitable species of algae are cut, dried, burnt, and the ashes treated for the recovery of sodium and potassium salts, iodides and iodine. This is wasteful, because the other minerals and the organic constituents are lost in the process. The kelp-burning industry became obsolescent when cheaper mineral sources of iodine were found, such as the nitrate deposits of Chile and the oil-well brines of California, and when underground deposits of potash were discovered and exploited. Kelp burning now persists only in a few places in France, in Japan, and perhaps in the Soviet Union.

In the United States, commercial harvesting of kelp began on the Pacific coast when World War I cut off the supply of potash, which had formerly been imported from Germany. Several factories went into the potash and iodine production business in California. One of them conducted intensive researches which led to the development of processes to extract a number of chemicals needed for war industries. Chief among these were acetone, acetone oils, potassium chloride, ethyl esters, and organic acids.[17]

But kelp is costly to harvest, and it contains so much water that it is costly to dry. Consequently, these American factories could operate profitably only during wartime. When the war ended, they closed for they could no longer compete with cheaper sources.

Seaweed manufacturers would have gone out of business long ago if iodine and potash were all that could be extracted from marine algae. In recent years they have been extracting from red and brown algae organic components called alginates, which are salts of alginic acid. This interesting chemical has the same function as cellulose in land plants; that is, it gives rigidity to the cell walls. It had been discovered in Scotland in 1883 but had remained unexploited for fifty years. The alginates have unique colloidal properties that make them valuable for a remarkable variety of purposes. Moreover, research going on in private factories, as well as in some European and Japanese governmental laboratories, is leading continually to new uses, new products, and improvements in production

processes. Alginate factories are now located in the United States, the United Kingdom, Norway, Spain, France, and Japan.

Chemists define alginic acid as a "hydrophilic colloidal polymer of anhydro-B-D-mannuronic acid units." These units are strung together into a chain of great length. The carboxyl groups of alginic acid react with ions of the alkali metals, as well as of ammonium, magnesium, and ferrous iron, to form the corresponding alginates. These are soluble in water and form viscous solutions at low concentrations. Alginates of other metals, on the other hand, are insoluble in water. The alginates have varying properties depending on the metal to which they are attached.[18] Thus an alginate product can be controlled by appropriate chemical treatment.

Algin is widely used in food industries, for making jellies, and as a stabilizer of ice cream, icings, malted milk, and cheese. It gives body to cake icings and fillings in which a softer gel is required than agar affords. It is used as an emulsifying agent in mayonnaise and other salad dressings. The non-food applications of algin are numerous. To mention only a few: pharaceutical emulsions, pills, tablets, and ointments, hand lotions, toothpaste, shaving cream, sizing material in the textile industry, paper coating, creaming of latex, leather finishing, and wire-drawing lubricant. All these uses are based upon the colloidal properties of algin as such and not upon the properties of algin derivatives.

British scientists in 1944 wrote, "It seems clear that alginic acid fulfills the main requirements of a substance intended for use in the manufacture of fibres. It consists of long chain molecules of high molecular weight possessing reactive side chains." [19] Unfortunately, threads prepared from sodium or calcium alginate are dissolved by soap and soda. In some instances this disadvantage can be turned to an advantage, for soluble yarns may be used in the manufacture of delicate woolen, silk, or rayon textiles or for obtaining special effects. And soluble sodium alginate can be transformed into insoluble alginates of beryllium, cobalt, copper, nickel, silver, bismuth, antimony, zinc, cadmium, aluminum, chromium, barium, and strontium. Of these the beryllium, cadmium, and chromium alginates are the most promising since they are noninflammable, are resistant to decay, and can be spun into fibres.

One or two factories in Great Britain are producing a small but steady quantity of soluble calcium alginate yarn. This is being used in the disappearing thread technique of manufacturing lightweight woolens. Despite a great deal of effort, however, they are finding that in the present state of our knowledge, metallic alginates do not compete successfully with the conventional fibers of wool

and cotton, nor with synthetics like rayon and nylon. This is because they are still too costly, they do not take a good color, they do not wear well, they vary too much in quality to permit satisfactory repeatability, and they have a relatively low dry strength and a very low wet strength. On the other hand they do have the advantage of being noninflammable, a property which alone may make it worthwhile to seek ways of exploiting these yarns further. Meanwhile, for general purposes, a great many technological problems will have to be solved before alginates can compete with other substances as raw material for synthetic fibers.

Red seaweeds have been used for 300 years in the manufacture of the gel-forming chemicals agar and carrageenin. Agar is extracted from a certain group of plants collectively called (by some botanists) the agarophytes, which includes various species of *Gelidium, Gracilaria,* and other genera. Carrageenin comes from "Irish moss" (*Chondrus crispus*). Both agar and carrageenin are sulfuric acid esters containing D-galactopyranose units joined by 1, 3-glycosidic linkages.[20] There are sufficient differences in structure, however, to give them differing properties and uses. Even agar itself varies in properties depending on its species, its place of origin, and the time of harvesting.

The properties of agar which give it unique value are its very high gel strength and the wide range of temperatures between the points of gelling and melting. A 1 to 2 per cent aqueous solution of agar, for example, solidifies at 35° to 50° C. and melts at 90° to 100° C.

Agar is a staple in bacteriological laboratories for making biological culture media. No satisfactory substitute for it has yet been found. It is also an excellent gentle laxative, and very popular in countries where over-refined foods seem to make such medicinals desirable. It is a principal ingredient in dental impression compounds to make a strong and rather elastic mould. Capsules made of agar are slow in dissolving and can be regulated in composition to carry a therapeutic agent past the stomach to a particular part of the intestine where it is needed.

In food industries, agar is added to cake icings to keep them from getting dry, brittle, or sticky. It is used as a stabilizer in sherbet, pies, meringues, mayonnaise, and salad dressing and as a gelling agent in jelly candies and similar confections. In canning industries it is added to meats, poultry, tongue, and fish to keep the product firm and in shape in the can.

Carrageenin is the gelatinous principle of "Irish moss," which is neither exclusively Irish nor a moss, but the red alga *Chondrus*

crispus. Although it is very similar to agar, it differs in having a lower gel strength and in certain chemical particulars, such as that it contains small quantities of z-keto-gluconic acid, glucose, and pentose and that its sulfuric acid ester group is attached to C_4 and not to C_6 as in agar. It requires a concentration of 3 per cent or more to form firm gels, and these liquefy at lower temperatures than do agar gels. Carrageenin is used as a stabilizer for chocolate milk, ice cream, sherbet, cheese foods, as a thickener for icings, pie fillings, puddings and similar confections, and as an emulsifying agent in hand lotions, insect sprays, and sizing materials. Its property of coagulating proteins gives it value as a clarifier for beer.

In Japan farmers cultivate red algae as a side line. In recent years this has become the most important of the marine culture industries, in terms of number of persons employed, acreage involved, and total quantity of material produced. The principal crop is laver (Porphyra), which, made into a dried product, is one of the most popular foods in Japan. It is not cheap, however, One sheet of dried laver costs almost as much in the retail market as a hen's egg. One method of culture is to collect the spores on bunches of bamboo sticks or twigs stuck into the mud in an area of high salinity at a level which is just covered at high tide. Some time after the spores settle the bunches are transferred to an area of lower salinity where the fronds grow large and tender.[21] Bamboo racks and coconut palm nets stretched between poles have become more important as spore collectors. Japanese prefectural governments have been attempting to improve laver farms by deepening suitable flats with bulldozers, surfacing the bottom with coarse sand, plowing, and directing channels of stream-fed water of high fertility along strategic courses.

There are waste products resulting from the manufacturing processes of algal industries for which uses have yet to be found. The structure of alginic acid itself is still only partly known, hence is variously described (see p. 284 for one example). R. H. McDowell says ". . . the best evidence indicates a long chain of the pyranose form of d-mannuronic acid, with glycosidic linkages joining the rings." [22] The structure usually assigned to alginic acid relates only to a small part of the whole molecule. As for the organic chemicals other than the alginates, methods for the preparation or extraction of mannitol, laminarin, fucoidin, D-glucose, L-fucose, and fucosterol have been developed in the laboratory. To find uses for these substances would require, first, a great deal of analytical research in chemistry, for the molecular structures are known for only a few of them; and, second, a great deal of technological research to develop economically feasible methods of mass production.

Perhaps the most difficult technological problem impeding the exploitation of algal resources is the high water content of these plants. One lot of fresh brown alga weighing 1,000 tons contained about 836 tons of water. It is often not feasible to remove this water by drying the weeds in the air, particularly in humid climates, and it is expensive to remove it with heat driers. So far, efforts to find other methods such as pressure, electro-osmosis, and plasmolysis, have not been very satisfactory.

Thus, by the time algae have been harvested, transported to a drying center, and dried, they have already become too costly for humble uses except in places where labor is plentiful and cheap. Even there it is not feasible to carry them far inland for agricultural applications. On the other hand, seaweeds contain materials having peculiar properties which make them valuable enough for the sophisticated needs of industrialized people to justify the high production cost. The extraction and refinement of these materials and the quality control of the final products require elaborate industrial establishments staffed with well-trained chemists. In general, these must be located near dependable sources of raw material, and they must also be near industrial centers where machinery, equipment, and skilled and professional workers are readily available. These requirements are strong obstacles to developing the use of seaweed resources in technologically backward areas.

Perhaps the most troublesome problem besetting people who manufacture algal products, as well as those who search for new uses of algae, is the variation in chemical composition of the plants. In many places botanists cannot tell how much geographic variation is attributable to ecological influences and how much to genetic differences in the stocks. On this question George F. Papenfuss of the University of California has written (in a personal letter):

> People come to me repeatedly for advice concerning the identity and the probable variability of the plants which they are investigating. They find that even common species, which presumably are well known, vary immensely in their biochemical properties; and the question arises whether or not they are dealing with one species or a complex of closely related species. In all instances our answer must be that we do not know, for the plants have never been adequately studied.
>
> Since a thorough knowledge of the plants themselves is in all instances a prerequisite to work on their physiology, biochemistry and possible use, I believe that in the long run, the best investment in seaweed research would be in the field of systematics.

Jean Feldmann writes:

> First of all it is necessary to complete our knowledge of the chief aspects and the characteristic formations of the marine vegetation of the areas of the

world which have not as yet been explored from this point of view. Up to now we possess detailed studies only for some favored regions. A more extensive survey of the marine vegetation would make possible detailed comparisons between the vegetation of widely separated regions situated in approximately the same latitudes and where, as a result, ecological conditions should be practically the same.

The vast majority of red algae are grouped in the subclass Florideae. This includes the agar-bearing plants. Concerning these, Kathleen Drew says, "The floridean algae of large areas of the world are still completely unknown." [23]

It appears, then, that the arguments advanced earlier (pp. 53 ff.) on the need for research in systematics are as true of the marine plants as of the animals. This kind of research is not nearly adequately supported by universities or by governments, nor is it likely to be financed by industrial companies.

The biology of seaweeds is another neglected field of research. The same kind of questions apply to them as to the marine animals. What characteristics of environment are critical to their existence and well-being? What are their rates of growth? What are optimum rates of harvesting? These are fundamental questions. Seaweeds have diseases. For instance, the red rot is one of the most serious problems of laver culturists in Japan. What are the vectors of such diseases? Seaweeds are also prominent elements in the ecology of inshore environments. On that ground alone we should no longer continue to neglect the study of these interesting and important plants.