BULLETIN No. 127

Marine plant resources of British Columbia

By Robert F. Scagel
University of British Columbia
Vancouver, B.C.

PUBLISHED BY THE FISHERIES RESEARCH BOARD OF CANADA UNDER THE CONTROL OF THE HONOURABLE THE MINISTER OF FISHERIES

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Seaweed garden at low tide, Hammond Bay near Nanaimo, B.C., June 2, 1961.
(Photo: C. J. Morley.)

A shell- and pebble-covered opening is margined above by eel-grass and the brown devil's apron (*Laminaria*). The broad fronds below are mostly green sea lettuce (*Ulva*), with the brown *Costaria* kelp at lower left, and small tufts of the introduced Japanese species of *Sargassum*. In the middle of the picture is a rather small plant of the bull kelp, *Nereocystis*; its float and slender stalk are to the right, its waving fronds to the left are about 3 feet long. Above it is an egg-ring of the moon snail, *Polynices*. Attached to a rock near the left margin is a tuft of the dissected agarophyte *Gracilaria*. Other marine plants growing luxuriantly in this area were the large red alga *Gigartina* and other smaller filamentous species.

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PART I. MARINE PLANT RESOURCES

INTRODUCTION

There is little doubt that there is in British Columbia a natural wealth in marine plant resources which by enterprising research could form the basis of an extensive industry. It was only nine years after the presence of algin was discovered in certain seaweeds that such an industry was first predicted for the Pacific Northwest. James G. Swan (1894), who had made observations on the kelp beds in this area, wrote as follows:

> During a residence of many years in the vicinity of Cape Flattery, at the entrance of Fuca Strait, I have had ample time and opportunity to observe the great masses of the giant kelp and other marine plants, which are torn up by the roots every fall by the storms, and piled by the waves along the beach at Neah Bay. I have frequently noticed, when a mass of this kelp has been thrown into a pool of fresh water, that in a few days it is covered with this slippery substance, . . . named algin, and I think that the *Nereocystis* is rich with this valuable ingredient. The supply of the raw material is practically unlimited, and if attention shall be directed to the valuable uses to which this plant and other algae may be put, I feel confident that a new and important industry will be developed, and we would all share in the satisfaction of knowing that one more waste product of the ocean can be effectually utilized.

Marine plants still represent an unexploited resource in British Columbia. However, they have been in the past and continue to be a basis for profitable industries in the United States (California and the Atlantic coast), Great Britain, India, Norway, Japan, Australia, New Zealand, Russia, South Africa, and in the maritime provinces of Canada. It is estimated that British Columbia has at least 16,900 miles of shore line (Fig. 1). Some efforts to explore this region and to estimate the value of the seaweed resources of the Province have been investigated from time to time. However, we are still a long way from realizing the full potentiality of this raw material. In a country and Province endowed with so many and varied natural resources, perhaps we can be excused for ignoring this marine plant resource at the moment. But the time will undoubtedly come when we will turn increasingly toward the sea in a search for new sources of carbohydrate, fat, protein, vitamins and minerals for food, as well as other products.

It will probably never be as easy to harvest marine plants as it is to harvest a field of grain, but they can be and have been collected, and under different kinds of economic conditions. Under some circumstances harvesting has been carried out by mechanical methods. In others it has been done by a sickle or hook or by hand. It is a challenge to the ingenuity of man that a material, of which millions of tons are produced each year along our coastline, is permitted to go almost entirely to waste. This is especially so when one realizes that the usable seaweeds are confined to a narrow band not more than a few hundred yards from the shore in many places.

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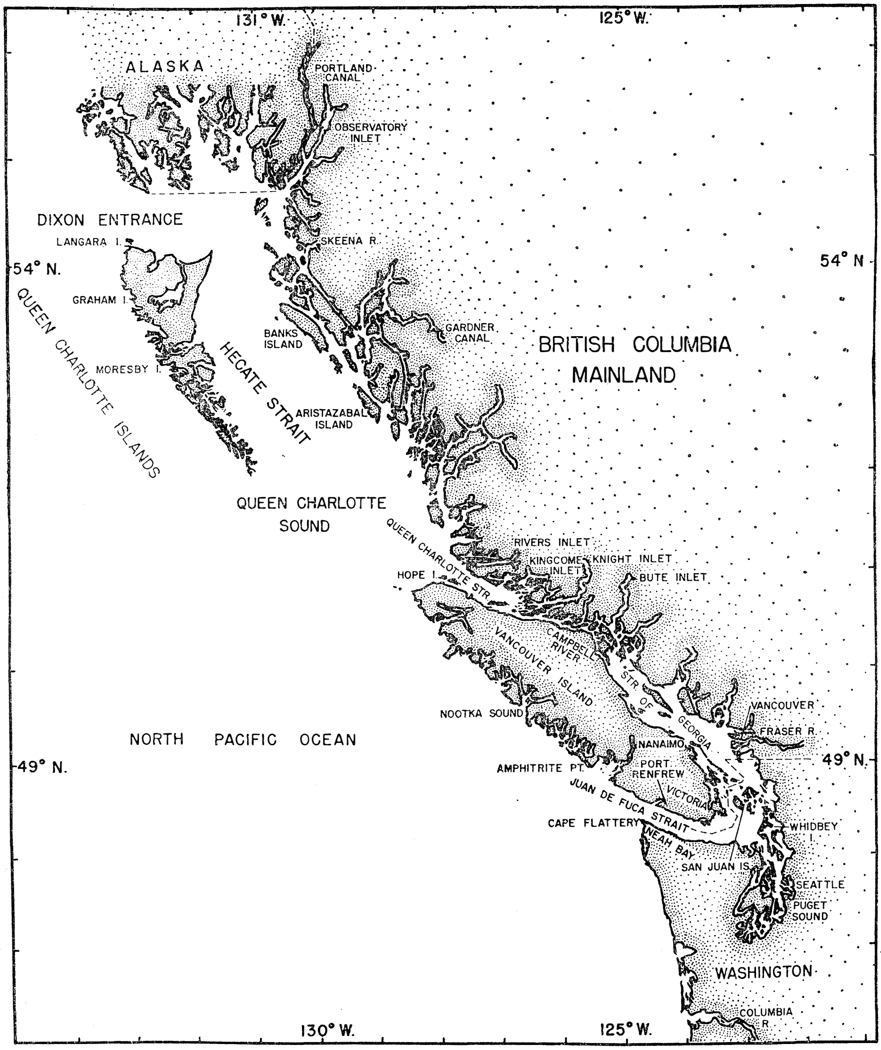

FIGURE 1. Map showing the extensive and dissected coastline of British Columbia.

In many respects man has conquered the land. In some instances, through greed or lack of foresight, he has destroyed some of his natural resources on the land. With the experience of our mistakes on the land behind us, there is every hope that a bright future exists for the fullest exploitation of our marine plant resources. But we must be constantly alert to the need for conservation measures. Our early errors in agriculture, forestry and fisheries—even some marine fisheries—have been severe lessons in experience. Exploitation of a resource without adequate conservation and development has almost always ended in disaster. Necessity has long proved to be the greatest stimulus to invention and we have every right to expect that man can surmount many of the mechanical and technical problems involved in the exploitation of this resource and a utilization of its products if he applies himself diligently to the task. It behooves us not to lose sight of the future of this resource and, moreover, to anticipate it.

It is only through the interest of many individuals that we may hope to make progress in our knowledge of the marine plants. The poorly known is apt to be uninteresting. And yet interest is often expressed from many sectors of the population—the farmer on the Saanich Peninsula, the fisherman in the Queen Charlotte Islands, the biochemist, the industrialist, the biologist, the dental technician—each making contact with the marine plants or their products directly or encountering reference to them in their various occupations. These interests vary greatly. Some are concerned with marine plants as a source of food—for man, stock, or fish. Others are interested in them as a source of fertilizers, plastics, or for many other purposes. It is to provide a ready source of reference to some of these varied subjects that this Bulletin is specially designed. The plants discussed comprise only those which are or have been used by man, either directly or indirectly. Many other seaweeds occur in British Columbia for which, at present, there is perhaps only fundamental scientific interest. These latter are not included, but for further reference material on the marine algae in this area the reader is referred to a more specialized paper in this connection (Scagel, 1957.)

MARINE PLANTS

Marine plants may be considered in two main groups: the marine grasses, which are seed-producing plants, and the marine algae. In this latter group there are two main types: the benthonic or attached algae, which are commonly referred to as seaweeds, and the minute pelagic or planktonic algae, referred to as phytoplankton. These latter include the diverse, microscopic, unicellular, filamentous or colonial plant or plant-like organisms passively floating or slowly swimming in the sea. All photosynthetic marine plants are capable of manufacturing their own food. Thus they are completely independent for the most part, and are either directly or indirectly the source of food for all living things in the sea.

There is no doubt that the plankton forms of algae, which include the diatoms and dinoflagellates, are the most important producers in the sea as a whole. These minute one-celled plants may occur at times in such abundance that they colour the water brown, red or green. Most of these plants are so small that they can be seen individually only with the aid of a microscope. Others are just visible to the naked eye. In addition to the very important diatoms and dinoflagellates, there are many other organisms that are a part of this pelagic group—members of the green algae, yellow-green algae, golden-brown algae, the reproductive stages (gametes and spores) of many of the benthonic algae and small benthonic forms which are torn loose and carried about by currents. Many of these are so small that they pass through the finest silk. Many are motile and possess whip-like flagella which lash about and bring about movement. The

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movements, however, are comparatively restricted and the organisms are more or less passively carried about by water currents. If one wishes to extend the definition of a plant, as some do, to include bacteria, these small organisms too may be present in the plankton, although they are more numerous on the bottom. Even though the phytoplankters are microscopic in size, a much greater area of the globe and volume of water is available for the support of pelagic plant life than for the benthonic algae. And so, although these organisms are exceedingly small, they bulk large in the general economy of the sea and are numerous in kind.

The benthonic or fixed marine plants, on the other hand, cover a small area, primarily because of the relatively limited area of continental shelf or water shallow enough to allow sufficient light for plant growth to penetrate. From this lower limit they may range to the highest tide level, or even above in the splash zone. The larger and more conspicuous seaweeds are usually fastened to the bottom by some means—often by root-like "holdfasts". Less than 8% of the oceans, including adjacent seas, have a depth shallower than about 650 feet, and algae seldom grow to this depth. Because of the many islands and inlets the length of Canada's Pacific coast line is not just a mere 500 miles—roughly the distance as the crow flies from Victoria to Stewart in northern British Columbia—but is estimated to be at least 16,900 miles. Under these coastal conditions benthonic marine plants make an important contribution to the economy of the sea. The marine grasses, and benthonic algae or seaweeds, are the only groups treated in detail here.

Some people also regard the marine grasses as "seaweeds". Since the two groups are quite unrelated it is more desirable to think of them as clearly distinct. This loose use of the term "seaweed" probably came about, just as on the land, through the use of the term "weed". We usually think of a "weed" as an undesirable plant. But a plant which is a "weed" in one locality may be a cherished and cultivated garden plant in another. Perhaps we can place the blame for this misunderstanding, in so far as the marine plants are concerned, as far back as the 1st century B.C. At that time the poet Virgil used the phrase *vilior alga*—more worthless than seaweed—while Horace wrote "tomorrow a tempest sent from the east shall strew the grove with many leaves, and the shore with useless seaweed."

Many of the early explorers and botanists—Columbus, Cook, D'Urville, Hooker, and Menzies (who sailed with Captain Vancouver)—made reference to seaweeds and even collected them. Many of these early travellers were impressed, as Darwin was in Tierra del Fuego, with the immense size of the giant kelp (*Macrocystis*). Darwin wrote as follows:

> There is one marine production which from its importance is worthy of a particular history. It is the kelp, or *Macrocystis pyrifera.* This plant grows on every rock from low-water mark to a great depth, both on the outer coast and within the channels. I believe, during the voyages of the 'Adventure' and 'Beagle', not one rock near the surface was discovered which was not buoyed by this floating weed. The good service it thus affords to vessels navigating near this stormy land is

evident; and it certainly has saved many a one from being wrecked. I know few things more surprising than to see this plant growing and flourishing amid those great breakers of the western ocean, which no mass of rock, let it be ever so hard, can long resist. The stem is round, slimy, and smooth, and seldom has a diameter of so much as an inch. A few taken together are sufficiently strong to support the weight of the large loose stones, to which in the inland channels they grow attached; and yet some of these stones were so heavy that when drawn to the surface they could scarcely be lifted into a boat by one person. Captain Cook, in his second voyage, says that this plant at Kerguelen Land rises from a greater depth than 24 fathoms: 'and as it does not grow in a perpendicular direction, but makes a very acute angle with the bottom, and much of it afterwards spreads many fathoms on the surface of the sea, I am well warranted to say that some of it grows to a length of 60 fathoms and upward.' I do not suppose the stem of any other plant attains so great a length as 360 feet, as stated by Captain Cook. Captain Fitz Roy, moreover, found it growing up from the greater depth of 45 fathoms. The beds of this seaweed, even when not of great breadth, make excellent natural floating breakwaters. It is quite curious to see, in an exposed harbour, how soon the waves from the open sea, as they travel through the straggling stems, sink in height, and pass into smooth water. The number of living creatures of all Orders, whose existence intimately depends on the kelp is wonderful. A greater volume might be written, describing the inhabitants of one of these beds of sea-weeds. Almost all the leaves, excepting those that float on the surface, are so thickly encrusted with corallines as to be of a white colour. We find exquisitely delicate structures, some inhabited by simple hydra-like polypi, others by more organised kinds, and beautiful compound Ascidiae. On the leaves, also, various patelliform shells, Trochi, uncovered molluscs, and some bivalves are attached. Innumerable Crustacea frequent every part of the plant. On shaking the great entangled roots, a pile of small fish, shells, cuttle-fish, crabs of all orders, sea-eggs, starfish, beautiful Holothuriae, Planariae, and crawling nereidous animals of a multitude of forms, all fall out together, . . . I can only compare these great aquatic forests of the southern hemisphere, with the terrestrial ones in the inter-tropical regions. Yet if in any country a forest was destroyed, I do not believe nearly so many species of animals would perish as would here, from the destruction of the kelp. Amidst the leaves of this plant numerous species of fish live, which nowhere else could find food or shelter; with their destruction the many cormorants and other fishing birds, the otters, seals, and porpoises, would soon perish also; and lastly, the Fuegia savage, the miserable lord of this miserable land, would redouble his cannibal feast, decrease in numbers, and perhaps cease to exist.

But these early explorers were chiefly interested in the seaweeds only as novelties, as bizarre forms of plant life or as navigational aids which indicated a proximity to land or reefs. In general, particularly in the Occident, a rather low regard for seaweeds has persisted for centuries. Not all the statements concerning marine plants can be complimentary. Some marine algae have been introduced directly or indirectly and become pests. For example, the Japanese species, *Sargassum muticum* (Fig. 2 and 3), has been introduced to British Columbia with the Japanese oyster, *Crassostrea gigas* (Scagel, 1956). In certain areas in the Pacific Northwest *Sargassum* is a nuisance to the oyster grower as well as to the fisherman and navigator. *Colpomenia*—sometimes called the oyster thief—is a pest on oyster beds in Europe. When the water is shallow or the tide out, this sac-like alga becomes filled with gas. On the return of the tide the inflated plants lift the young oysters to which they have become attached and float them out to sea. In France, workmen attempt to free the oysters from the pest by dragging nets or ropes over the oyster beds. There is some reason to believe that the species found in the Pacific (*Colpomenia sinuosa*) was introduced from Europe, although the oyster growers on the Pacific coast of America have apparently experienced little trouble from this particular alga.

DISTRIBUTION AND ECOLOGY OF MARINE PLANTS

Just as a variety of conditions on the land is reflected by a diversified flora and fauna, so too in a marine environment certain plants require a specific set of environmental factors. With a variety of oceanographic conditions we would expect great variation in the distribution and kinds of marine plants owing to their physiological requirements, tolerances, and mechanical adaptations. And such is the case. Much of our information concerning these distributions is still observational and indirect—a correlation of plant occurrence with conditions observed in nature—and there remains much to be explained. It is difficult, however, to carry on experiments with large marine organisms under adequately controlled conditions to test many of the hypotheses based on field studies.

Because of the geographic position of British Columbia and the oceanographic conditions associated with the coast in these latitudes, we have algae in our marine flora which are typically Arctic forms—at their southern limit in British Columbia; and on the other hand there are algae more typical of the semitropical latitudes—at their northern limit in British Columbia. The variety of coastal oceanographic conditions in British Columbia is probably not exceeded in any other part of the world. The temperature of the water in a region such as Haro Strait, where the water is well mixed, may not rise even as high as 52° Fahrenheit near the surface in the summer, and yet at the northern end of the Strait of Georgia (Fig. 1) in some of the larger protected bays temperatures may rise to over 70° near the surface—almost as warm as any inshore coastal water encountered on this Coast north of southern California. Similarly, because of the many large rivers emptying into the sea in British Columbia there are conditions ranging from full ocean salinity to local areas where the salinity is greatly reduced or brackish in the river estuaries.

Most marine organisms have fairly narrow limits of tolerance. Certain marine plants are characteristic of waters of high salinity, others may extend into brackish zones or fresh water. The salt content of the oceans is generally between 33 and 37 parts per thousand, with 35 considered as an average for all the oceans. The surface salinity may be considerably less near the poles or in regions of high rainfall; in British Columbia it ranges from about 33 down to 0 (fresh water) near the river mouths and at the head of the inlets. Only in isolated lagoons or seas, such as the Red Sea, where evaporation is excessive, does the salinity reach as high as 40 parts per thousand.

The coastal topography of British Columbia varies from soft muddy and sandy flats and beaches to shores with gravel, pebbles, boulders and rock with smooth or rough surfaces. One is often inclined to think of the sea in contrast to the land as a more uniform environment—chiefly because many of us visit only the tourist beaches. But beneath the sea the topography and substratum is equally varied. However, the shoreline in British Columbia is predominately rocky. The greatest number of species and individuals live on the rocky shores. The mud flats and sandy beaches have few seaweeds because of the unstable nature of the bottom. The physical nature of the substratum, particularly as an anchoring surface, may profoundly affect the distribution of some marine plants—particularly the larger forms. The smoothness or roughness of rocky surfaces may determine the type or size of plant which may be supported. The strength of currents or tidal action may likewise affect the distribution of marine plants. These plants, with the exception of the "grasses", do not have true roots. However, they may have root-like structures called holdfasts, which serve as an anchoring mechanism, to hold them in a desirable position.

In some instances the bottom slopes off gradually to a mile or more from shore, in others it falls precipitously to great depths. The exposure is varied from areas fully protected, as in Sooke Harbour or Vancouver Harbour, to the moderately heavy wave action in inland passages, and to the full ocean surf conditions on the west coast of Vancouver Island and the Queen Charlotte Islands.

The vertical distribution or zonation of marine algae is frequently very marked. This distribution of a marine plant may be in part controlled by the amount of light it requires, by wave action or ability to withstand freezing or desiccation. Since energy for the synthesis of food substances by marine plants comes from the sun the degree of penetration of sunlight into water is of major importance. Since the depth at which an alga grows depends on available light, the distribution of these plants may also vary with latitude. In lower latitudes light can penetrate to a greater depth than in higher latitudes. There may be specific light requirements of intensity, quality, and perhaps even duration. Although in the Mediterranean, where the water is highly transparent, benthonic algae are reported at depths approaching 300 feet, in our part of the northeastern Pacific where the waters are rather turbid the depth to which there is any significant algal development on the bottom is considerably reduced and generally does not extend below 100 feet.

The marine plants in the highest zone on the shore live above high-tide mark and may only be splashed with water occasionally. Others live farther down the shore and are seen only when the tide is unusually low. Still others are always submerged and may be seen only by diving, or when they are dredged up or torn from their holdfasts and swept ashore by storms.

The greatest variety and the greatest number of seaweeds can be observed when the tide is low (Fig. 4). In some regions tides reach their high and low levels twice each day, and on each succeeding day these extremes usually occur about 50 minutes later. In many regions high or spring tides come monthly, when the moon and sun are in conjunction at new and full moon, and alternate with minimal or neap tides, when the forces are in opposition near the first and third quarters of the moon. In the southern portion of British Columbia, however, declinational effects tend to obscure this pattern to a considerable extent. Because of this continuous ebb and flow of the tides, the seashore affords a variety of distinct habitats. The algae that live in the regions extending b the limits of the high and low tides must be able to survive periods of exposure of varying duration. These periods of exposure may bring about marked changes in temperature and salinity. Because of the relative constancy of physical and chemical conditions in the sea, climate does not generally play as direct a part in the distribution of algae as it does in land plants. However, in this intertidal area the presence of fog, intense sunlight, rain, wind and frost may have a profound effect at certain times on the distribution of the marine algae. The ability to resist such periods of exposure varies with the different algae. Some species of algae may survive many days continuous exposure, whereas a few hours is sufficient to cause death to others. The wide distribution of a species may be prevented if its spores can survive only a short period of time without finding suitable places for attachment.

Because there are no true roots, stems or leaves and little evidence of conduction in the algae, the whole plant must be bathed in water for at least the greater part of the day in most instances, in order to obtain necessary inorganic materials for plant growth directly through its surfaces. Seaweeds, as well as marine plants in general, grow abundantly, however, in the proper environment—wherever there is a suitable substratum for attachment, adequate illumination, optimal temperatures for growth and reproduction and a constant supply of inorganic nutrients and growth substances. Such conditions are found in the shallow waters of the continental shelf where drainage from the land, turbulence and upwelling of deeper, nutrient-rich water provide the necessary constituents for photosynthetic organisms.

In addition to the marine forms of algae, there are others which inhabit our freshwater ponds, lakes and streams, the soil, hot springs or snow, up to high altitudes in the mountains. These forms, like the marine phytoplankton, are mostly either microscopic or appear to the naked eye as masses of filaments or slime. They can be identified only with the aid of a microscope.

One must consider the requirements of marine plants throughout their life history in assessing their ecological requirements. Cyclic changes such as rhythms in response to temperature changes, or light changes, may affect their behaviour. One set of environmental factors may suffice for the juvenile stages but be unsatisfactory for the development of the mature stages or other phases in the life history and result in a sterile distribution. Establishment of the juvenile stage from seeds (in the case of the marine grasses) or spores (in the case of the algae) may depend largely on conditions permitting the organisms to become established and in some instances may be fortuitous.

Although in British Columbia we find a great variety of oceanographic conditions, there are usually no widespread extremely high or extremely low temperatures. In general the water along the coast is cold even near the surface and, on the average, ranges from about 52° Fahrenheit in summer to 40° in winter. However, in localized bodies of water such as tidepools the extremes of heat and cold may be more marked. The tidepools frequently show an interesting distribution of algae which differs markedly from that on the rocky shore nearby. In the deep pools there may even be some vertical zonation. The algae in these tidepools do not dry out; but in the higher pools, which are exposed for longer periods during a low tide, in addition to undergoing extreme temperature variations they are also subjected to considerable changes in salt and hydrogen ion concentrations.

MARINE GRASSES

The marine grasses comprise the rooted aquatic vegetation on the coast of British Columbia. They are not true grasses but closely resemble them through the grass-like character of the long, narrow leaves. They produce roots, stems, leaves, flowers and seeds, just as do the higher land plants. These marine grasses belong to a group of plants which has become thoroughly adapted to life in the water. They appear to be migrants from fresh water, where their nearest relatives occur, the pondweeds. The flowers are pollinated under water by the aid of water currents.

Although there are a number of different genera which have adopted this marine habitat in other parts of the world, particularly in the Southern Hemisphere, on the coast of British Columbia only two are known; namely, *Zostera* and *Phyllospadix.* Both are perennial and have rhizomes, or prostrate stem-like shoots, which grow longer and produce new sets of roots and leaves each year.

Zostera is commonly known as eel grass, but sometimes is referred to as seagrass, crab grass and grass-wrack. The species on this coast is *Z. marina* L. (Fig. 5).

Phyllospadix is most commonly known as surf grass, but also is referred to as false eel grass and basket grass. There are two species known on this coast; namely, *P. scouleri* Hooker and *P. torreyi* Watson.

Zostera marina L. is the basis of important industries in Great Britain, France, Holland and to some extent on the Atlantic Coast of North America. After mowing the eel grass with scythes at low tide, the harvesters spread it in the fields to partially dry. Then it is soaked for a few days in fresh water and finally thoroughly dried and pressed into bales. This product is used as a substitute for hair for stuffing mattresses and furniture, and also has been used for household insulation. Although it contains only a small amount of fiber, a high quality paper has been manufactured from it. Following the almost complete eradication of eel grass from the Atlantic coast by a wasting disease in 1931–32, the latter area lost this industry. There is still evidence of persisting disease, and eel grass has not yet returned to its former luxuriance on the Atlantic Coast, although it is gradually being restored. The organism responsible for this disease is believed to be a microscopic, fungus-like form, *Labyrinthula.* This organism has been found on numerous marine algae as well as on eel grass along the Pacific coast, but it has never increased here to the point of causing an epidemic.

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Phyllospadix has apparently not been used for the same purposes as *Zostera*, probably because it does not occur in the Atlantic areas where an industry exists. It would probably serve equally well.

Both *Zostera* and *Phyllospadix* have been used by the Indians on the Pacific Coast to some extent for basket-weaving.

Some attempts have been made to feed *Zostera* to stock but results have been inconclusive as to any nutritional benefit.

A brief description of the two genera and species follows:

Zostera marina L. extends all along the Pacific Coast of North America from San Diego to Alaska and is similar to the eel grass of the North Atlantic. The common plant is sometimes referred to on the Pacific Coast as *Z. marina* var. *typica* Setchell (more accurately, *Z. marina* L. var. *marina*). In addition, we have a larger, broader-leafed form known as *Z. marina* var. *latifolia* Morong.These two forms occupy quite distinct zones and can generally be distinguished on this basis. Both occur in the waters of protected bays and usually form dense beds over muddy bottoms. Their roots and creeping rhizomes are generally embedded in the mud. The narrow-leaved form is found in shallow water, from about 2 feet above to 3 feet below extreme low tide level. The leaves are usually about $\frac{1}{4}$ inch wide, have 3–7 longitudinal veins, and may be up to 4 feet long. The broad-leaved variety is a deeper-water plant generally, and is larger in all respects. The leaves reach lengths of 10 to 13 feet, are $\frac{1}{4}$ to $\frac{1}{2}$ inch wide, and have 3–7 veins. The plants grow from about low-tide level down to about 20 feet deep on a muddy bottom.

The genus *Phyllospadix* is confined to the North Pacific Ocean. One species is recorded in Japan and two on the west coast of North America. Although *Phyllospadix* possesses many of the grass-like characteristics of *Zostera*, this genus differs markedly from the latter in its habitat. *Phyllospadix* occurs characteristically on rocky wave-swept shores and is attached to the rough rocks by means of its creeping rhizomes. In contrast to *Zostera*, which is generally a pale, dull-green colour, *Phyllospadix* is a bright emerald green.

Phyllospadix scouleri Hooker is most characteristic of the open, rocky shores of the coast which are exposed to the full force of the waves, as on the west coast of Vancouver Island. Here it forms bright emerald-green beds on the rocks near extreme low-tide level. The plants are relatively short, usually not more than 3 feet in length and the leaves are 1/12 to 1/8 inch wide. Short basal flowering stems are produced which are 2–3 inches long.

Phyllospadix torreyi Watson is also found on the open rocky coast but, in contrast to *P. scouleri*, it is usually in deeper water or in deep rocky pools protected from the full force of the waves. It is a larger plant than *P. scouleri* and reaches a length of nearly 10 feet. When mature, the leaves are wiry and less than 1/12 inch wide. Mature leaves tend to be more oval or circular in cross-section than the flattened leaves of *Zostera* and of *P. scouleri*. Long basal flowering stems are produced which are about 12 inches in length.

MARINE ALGAE

Marine algae include green algae (Chlorophycophyta), brown algae (Phaeophycophyta), red algae (Rhodophycophyta) and blue-green algae (Schizophyceae).

The *green algae* are of little economic value, although some are used as food in certain countries. However, they include some important fouling forms, such as *Enteromorpha*, *Chaetomorpha* and *Cladophora*. The *brown algae*, which are characteristically found in abundance in cold waters, include the giant kelps and intertidal rockweeds. These and red algae are of considerable economic importance largely because of the properties of the complex colloidal carbohydrates which occur in their cells. The *red algae* are most varied and abundant in the tropics, but are also plentiful in colder waters. The *blue-green algae* are cosmopolitan, but they do not include any large conspicuous forms.

Although seaweeds are less diverse than land plants, there are almost endless variations in pattern and complexity of cell arrangement and growth habit. They range from one-celled organisms, through colonial types, then, in increasing complexity, through simple or branched rows of cells (filaments) and finally to elaborate structures attaining a size and intricacy that vie with those of flowering plants. Some of the kelps, such as the olive-brown oarweeds, or *Laminaria* (Fig. 6), may be only a few feet in length whereas others, such as *Macrocystis* (Fig. 7, 8, 9), may reach a length of 100 feet or more along the Pacific Coast of North America and weigh as much as 75 to 100 pounds each. Some of our most attractive plants are algae. They do not produce flowers, but shape, symmetry and colour combine to form some very beautiful as well as bizarre plants. Many red algae, in particular, make admirable herbarium mounts which will retain their natural colour and beauty for many years when properly stored.

The separation of the groups of algae on the basis of colour may seem superficial, but with some few exceptions, fundamental biochemical characteristics support this division. Chlorophylls are present in all these groups, but in the brown and red algae the green pigment is masked by accessory pigments—brown, blue and red—which give the distinctive colours to the various groups.

The blue-green algae are little more than slimy growths of microscopic, unicellular, filamentous or colonial structures. Where present in sufficient abundance, however, they may appear as dark blue-green, green, black or even red masses. Generally they are among the less conspicuous forms. The green algae, on the other hand, in many instances are commonly encountered and recognized macroscopically as individuals, as are also many of the browns and reds.

Whereas the blue-greens are rather cosmopolitan, one encounters the other three groups along the seashore in rather definite zones in a striking vertical distribution. These bands or zones overlap to a considerable extent, and although there are certain exceptions, the greens most commonly occur in the upper intertidal area, the browns in the lower intertidal, and the reds from the lower intertidal down into deeper water. It is noteworthy that where exceptions occur

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in this vertical distribution, variations in the basic colour occur. The reds, for example, which are found in the upper intertidal area may be dark purple, greenish or almost black. The browns occurring in the upper intertidal area may be almost yellowish or greenish, while those in deeper water below the intertidal zone are frequently almost black. These modifications (often in the same species) apparently come about through the variation in the relative amounts of the different pigments present in the algal cells and are in response to variation in light conditions.

One may look at these major groups of algae from the point of view of the systematic botanist; or as an ecologist—from the standpoint of associations; or as a conservationist—as a source of protection, a breeding area or food supply for various animals; or as an oceanographer—as contributors biologically, chemically, physically and geologically to the marine environment; or as an economist—in regard to what they may provide as a natural resource; or as a biologist—concerning how to properly exploit and conserve these resources, and what effect exploitation may have on other marine resources.

As previously mentioned, marine algae may be classified as *benthonic* and *pelagic*, according to their habitat. The benthonic forms, even in coastal regions, do not contribute directly to the food of animals to the extent that the pelagic group or phytoplankton does, but they contain a great mass of stored energy which can be broken down by bacteria. Many benthonic algae are annuals, so there is a rapid turn-over. These plants provide detritus which is used as food by benthonic animals as well as pelagic or free-swimming organisms. Unless one has seen the abundance of material that can be thrown up on the beach by winter storms, for example in Queen Charlotte Strait, one cannot appreciate how much material is produced in and eventually returned to the sea through this means. At times seaweeds may be piled up 10 to 12 feet high on the beaches.

Among the more conspicuous and abundant marine algae on this coast are *Nereocystis* (Fig. 10, 11) and *Macroystis* (Fig. 7, 8, 9). *Nereocystis*, which is obvious at almost any stage of the tide, is one of the more important of the larger seaweeds. This plant is essentially an annual and the novice would probably not recognize it as the same plant in its juvenile condition. However, by June, or somewhat earlier, it becomes very conspicuous and on certain parts of the coast of British Columbia forms beds of a considerable size. These beds are often sufficiently dense to form natural breakwaters. The plants grow with their holdfasts fastened to rocks and for this reason form danger signals to mariners with respect to the depth and nature of the bottom. Later in the season, or after heavy storms, large masses of these plants may break loose and float about on the surface of the ocean for many miles and far out to sea. The individual plants may weigh as much as 25 pounds or more. The spores are produced in groups on the long flat blades and mature by midsummer, appearing as dark patches. The stipe, or stalk, may reach a length of 100 feet and grow in water to 10 fathoms in depth. *Nereocystis* is commonly known as the bull kelp, bladder kelp, ribbon kelp, sea otter's cabbage, sea whip or sea onion.

Macrocystis is perhaps the most important seaweed present on our coast. It too is very abundant, but is restricted to areas near the open ocean. The plant grows attached to large rocks, and is commonly known as the giant kelp or kelp flag because of the way the leaf-like blades at the surface of the water dance in the breeze and wave over and over. The species found on this part of the coast occurs usually inside an outer protecting fringe of *Nereocystis* and grows from zero tide level or slightly above, down to a depth of about 30 feet. The plants may have stipes or stalks as long as 100 feet with as many as 13 or more of these arising from a common holdfast. The plants may weigh as much as 100 pounds each. There are bladders or air floats at the base of the leaf-like portions. Since fertile portions of the plant bearing these bladders may float about after breaking off, dissemination of spores may be aided by these structures. The spores are borne on both surfaces of basal leaf-like structures in dark, thick patches. This plant also occurs in natural breakwaters and provides a signal to mariners, indicating the presence of a rocky bottom.

Nereocystis can be used to illustrate one type of life history found among brown algae. This plant has an astronomical reproductive potential. It is essentially an annual, and the conspicuous "sporophyte" generation is reproducing at its peak rate between about June and September. It may also reproduce to some extent throughout the winter months. There are about 6,000,000 *sporangia* formed per square inch of surface in the fertile regions on the broad, ribbon-like blades, each of which releases 32 motile *zoospores*. Both surfaces of these spore-producing regions are fertile and about one third of the surface area of every *lamina* or blade on the plant may be fertile. There may be 20 or more laminae on each plant. The laminae may grow at a rate of 2 inches per day, average 6 inches broad, and may be 14 feet long by the end of the growing season. Thus in one season a single plant may produce about 3,700,000,000,000 zoospores. These motile reproductive cells are potentially capable of developing into a small filamentous "gametophyte" stage, that is usually not noticed. The gametophytes are of two sexes, male and female, and may be perennial. Gametophytes of some closely related forms have been kept growing under observation for at least 3 years. Usually several eggs are produced and fertilized on each female gametophyte. However, even if only one egg per plant were fertilized, 1,850,000,000,000 new sporophytes could theoretically result from one original kelp plant.

Macrocystis is much like *Nereocystis* in its life history, although it is essentially perennial from the base. *Macrocystis* cannot withstand the full force of the surf as well as *Nereocystis*, but during some phase of its life history it apparently requires conditions—perhaps higher salinity—that are associated with the open ocean, since it does not occur in the inner passages of the coast.

Many of the red algae have a life history similar to *Rhodymenia*, a genus to which the common dulse belongs. They are even more prolific than the brown kelps. A broad foliose species, such as *Rhodymenia pertusa*, produces about 60 *cystocarps* per square inch of surface of the female gametophyte plant (Fig. 12).

Each of these reproductive cystocarps may produce several hundred *carpospores*. A plant of average size probably produces about 12,000,000 carpospores, as a very conservative estimate. Each carpospore is potentially capable of growing into a sporophyte plant of the same size and appearance as the gametophyte plant. The sporophyte plants may produce 100,000,000 *tetrasporangia* apiece. Thus there could result about 1,200,000,000,000,000 tetrasporangia, each of which in turn may give rise to four *tetraspores*. Finally, each tetraspore can develop into a gametophyte or sexual plant, so that potentially there could result 4,800,000,000,000,000 plants—half male and half female—from the original female plant.

Obviously these motile or mobile stages have a tremendous mortality rate and undoubtedly they are important in the diet of filter-feeding organisms living in the sea. In this sense the fixed plants are not only primary producers on the bottom, but also may be primary producers comprising a part of the phytoplankton at some stages during their life history.

POTENTIAL RESOURCES IN BRITISH COLUMBIA

The present value of the seaweed resources of the Province can only be roughly estimated from the available information on the "standing crop". The future sustained yield from this standing crop will be determined by the development of suitable culture and harvesting methods, and proper management and conservation. Under such a program the present standing crop might be not only maintained, but increased. Only preliminary surveys have been carried out, and these have not covered all portions of the coast or all species of economic value. Although aerial surveys and the echo-sounder have been used with success in some parts of the world to evaluate seaweed resources (Chapman, 1944), these techniques have been used only to a limited extent for this purpose in British Columbia. Any estimates given, therefore, are based on incomplete information and are necessarily qualified.

The major seaweed resources may be divided into two general groups—the alginophytes and agarophytes. The former includes the more conspicuous forms of brown seaweeds commonly designated as "kelp", whereas the latter includes a number of red seaweeds which are generally smaller in size but of considerable importance. Alginophytes known to occur in considerable quantity in British Columbia waters belong to the following genera of kelps: *Macrocystis*, *Nereocystis*, *Laminaria*, *Alaria* (Fig. 13), *Hedophyllum*, and a few other less conspicuous forms.

ALGINOPHYTES

One of the early surveys of the extent of the beds of marine plants in British Columbia was carried out in 1914 for the Biological Board of Canada (now the Fisheries Research Board of Canada) by A. T. Cameron (1916a). This report contains two charts of the extent, and probable yield per acre, of kelp beds on the northeast coast of Vancouver Island, together with observations of the beds elsewhere along the coast almost to the Alaska boundary.

During the summer of 1946 the British Columbia Research Council and the Fisheries Research Board conducted a joint survey of coastal waters (except for the west coast of Vancouver Island, the Queen Charlotte Islands and some of the more isolated areas) during which estimates of the more readily harvestable and accessible floating forms of kelp—*Macrocystis* and *Nereocystis*—were made (Anon., 1947, 1948). From these records and some previous surveys in the Gulf of Georgia by the British Columbia Research Council, standing crops of *Macrocystis* and *Nereocystis* were estimated as in excess of 22,500 and 370,000 tons respectively. These tonnages were regarded as decidedly conservative. A more detailed investigation in the vicinity of Hardy Bay (Scagel, 1948), made for the Provincial Fisheries Department, suggested that the figure for *Macrocystis* was perhaps half or a third of the true value because of the unfavourable stage of tide at which it had been necessary previously to examine many of the beds of floating kelps. The *Nereocystis* figures also proved too low. On this basis, and in consideration of the areas not yet examined in detail, it is highly probable that the amount of floating, readily accessible kelps available in British Columbia waters may approach 750,000 to 1,000,000 tons annually. In addition many of the smaller kelps, although presenting more difficult collecting problems, are also valuable sources of algin and are more widely distributed. It seems probable that the addition of these smaller forms, such as *Laminaria*, *Alaria* and *Hedophyllum*, may bring the total kelp available on this coast to at least 1,500,000 tons annually. Other estimates have suggested that 3 to 20 times this amount is to be expected (Hutchinson, 1953).

Large beds of *Macrocystis* and *Nereocystis* are present at the north end of Vancouver Island and to some extent along the west coast of Vancouver Island. These same genera are very abundant in the Prince Rupert area around Stephens, Dundas and Porcher Islands, around Banks and Aristazabel Islands, and are also known to be present in quantity off the Queen Charlotte Islands.

Agarophytes

Gracilaria (Fig. 14) and *Gracilariopsis* are fairly abundant in British Columbia, especially along the southeast coast of Vancouver Island. Under favourable conditions they grow rapidly and reach a remarkable length. Other species of agarophytes are also known in these waters. As yet abundance and distribution have not been determined comprehensively for any agarophyte.

Reproduction in Relation to Harvesting

Management measures both for alginophytes and agarophytes will rest primarily on an understanding of their reproductive characteristics and a knowledge of the periods at which reproductive structures (spores and gametes) are liberated. From *Nereocystis*, which is essentially an annual, only one harvestable crop a year can be obtained. Thus it is necessary either to leave portions of the seaweed beds uncut, or to delay cutting until reproduction has been permitted to the extent needed for replacement. On the other hand *Macrocystis* is perennial, at least from the base, so that proper cutting policies may allow more than one harvest in a season without damage to the reproductive parts (Scagel, 1948). Agarophytes, and red seaweeds in general, have additional complexities in their cycles (Smith, 1944) which must be studied and understood in order to determine possible methods of culture and the best season at which harvesting can be accomplished.

In most of the higher forms of algae there are two sexes, so that if one sex or stage is largely removed the existence of the plant might be endangered. In many there is also a phase in the life cycle that produces reproductive stages called spores. If such plants were harvested before the reproductive cells are liberated, a deleterious effect on continued crops of seaweed might result.

Encouraging Utilization

The development of marine plant resources might be encouraged by (1) acquiring an accurate estimate of the amount of the economic species known to be present on this coast in abundance, (2) determining the distribution of other species, particularly agarophytes, about which we know extremely little except for *Gracilaria* and *Gracilariopsis*, (3) investigating appropriate methods for their collection, (4) studying the growth of the commercially important species, (5) observing the seasonal variation in the stocks, and the recovery of beds after harvesting by different methods, (6) studying the variation of chemical composition of different algae at different seasons, in different habitats, at different depths, at different ages and under various other environmental conditions, (7) correlating management measures with life-history details, and (8) introducing an educational program to acquaint the public with this practically untouched resource and the wide range of uses to which its products may be put.

Many of the special uses of seaweeds and other marine plants are probably quite profitable, and certain commercial products such as agar and algin, which are obtainable only from seaweeds, are in great demand. The manufacture of certain products formerly obtained from seaweeds, such as potash salts and health "foods", is of doubtful practical importance except perhaps as by-products, since there are now more economical sources of such materials.

Harvesting and Processing

One of the principal problems in exploiting seaweeds is the cost of harvesting. In most instances 10 tons of wet kelp must be harvested in order to secure about 1 ton of dry seaweed. Gathering by hand, from the shore or small boats, involves high labour costs and is at present impractical on the Pacific Coast. Hence a first step toward an economic operation must be the development of an efficient mechanical harvester.

After harvesting, it is necessary to subject the seaweed to some form of preliminary processing, such as partial or complete drying, so that shipment to a processing plant for further treatment can be made economically. The drying of kelp and other seaweeds in the open air is rarely feasible in the climate of the British Columbia coast, and artificial drying presents difficulties for which special facilities are not at present strategically located on the coast. However,

FIGURE 2. *Sargassum muticum* (Yendo) Fensholt, shown amongst *Zostera* in a lagoon, is common in warm bays in the southern part of British Columbia.

FIGURE 3. Branch of *Sargassum muticum* (Yendo) Fensholt, a plant introduced accidentally with the Japanese oyster, showing spherical air-bladders which permit the plant to float. ($\times \frac{3}{4}$).

FIGURE 4. Dense bed of marine algae shown at low tide off Pulteney Point, Malcolm Island, in Queen Charlotte Strait. In the foreground, species of *Laminaria* and *Alaria;* in the background, the floating kelp *Nereocystis luetkeana* (Mert.) P. & R.

FIGURE 5. Basal part of eel grass, the grass-like seed plant *Zostera marina* L. var. *marina*, which is common and widespread on muddy bottoms of protected bays. (× ½).

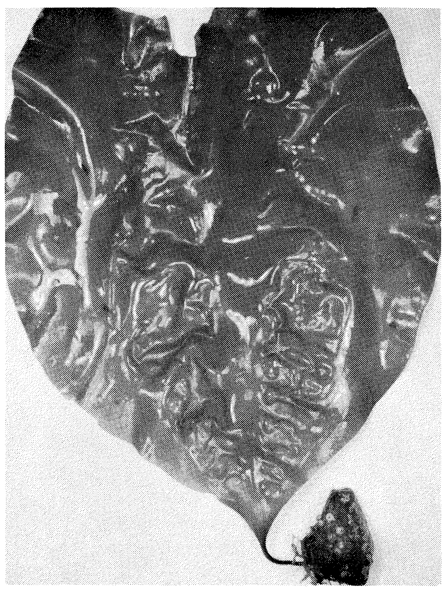

FIGURE 6. The common and widespread kelp *Laminaria saccharina* (L.) Lamour. f. *saccharina* showing flat ruffled blade and basal root-like holdfast attached to a pebble. (× ⅓).

FIGURE 7. Dense bed of the kelp *Macrocystis integrifolia* Bory at low tide off Deer Island near Port Hardy. This seaweed is found only in regions on or within the influence of the open coast.

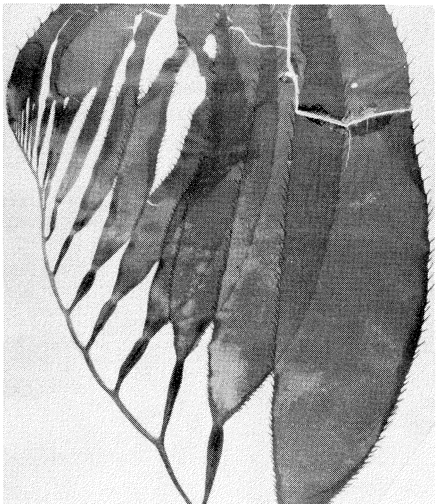

FIGURE 8. Terminal portion of a branch of the kelp *Macrocystis integrifolia* Bory showing air float at base of each leaf-like blade. ($\times \frac{1}{3}$).

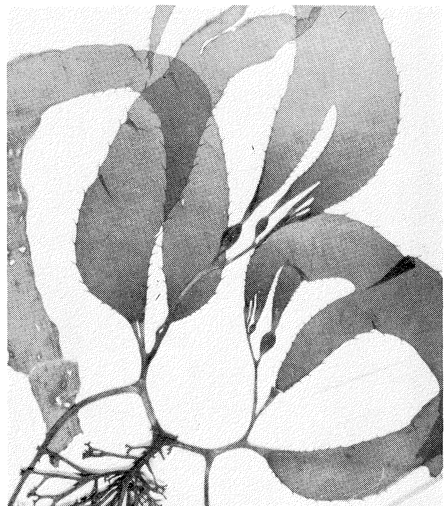

FIGURE 9. Basal portion of a plant of the kelp *Macrocystis integrifolia* Bory showing root-like holdfast and narrow branches arising from it. ($\times \frac{1}{3}$).

FIGURE 10. Dense bed of large plants of the kelp *Nereocystis luetkeana* (Mert.) P. & R. in Dixon Entrance at the north end of Graham Island in the Queen Charlotte Islands.

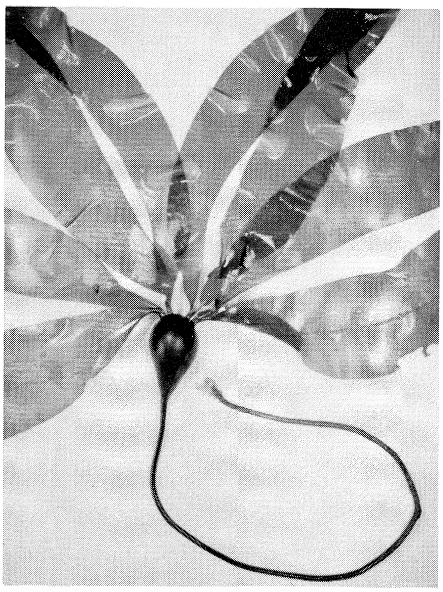

FIGURE 11. A small specimen of the common kelp *Nereocystis luetkeana* (Mert.) P. & R. showing large air float bearing numerous flattened blade-like laminae. ($\times \frac{1}{5}$).

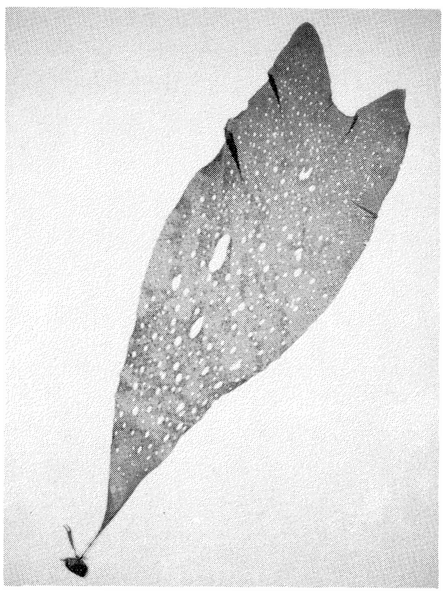

FIGURE 12. A mature female plant of the red alga *Rhodymenia pertusa* (P. & R.) J. Ag. which is generally subtidal. The small dark spots are cystocarps bearing carposopores. ($\times \frac{1}{4}$).

FIGURE 13. The basal part of the kelp *Alaria marginata* P. & R. which is subtidal or occasionally exposed in the lower intertidal region showing leaf-like spore-bearing branches arising from the stalk. ($\times \frac{1}{3}$).

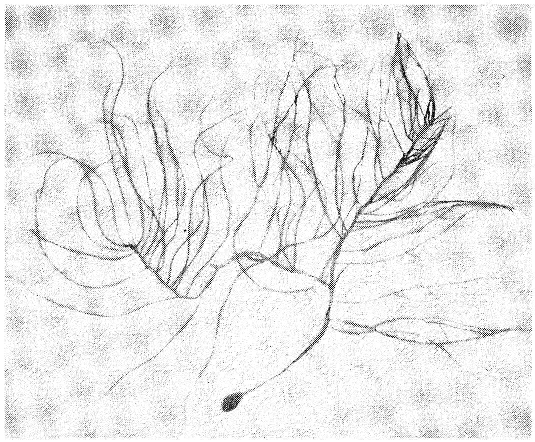

FIGURE 14. A mature plant of the agarophyte *Gracilaria verrucosa* (Hudson) Papenfuss shown attached to a small pebble. It is common throughout the coastal region in the lower intertidal and upper subtidal regions. ($\times \frac{1}{3}$).

FIGURE 15. A mature plant of the common rockweed, *Fucus*, showing swollen branches with irregular surface of reproductive structures. ($\times \frac{1}{3}$).

FIGURE 16. The membranous purple laver, *Porphyra perforata* J. Ag., a common and widespread plant in the upper intertidal region. ($\times \frac{1}{4}$).

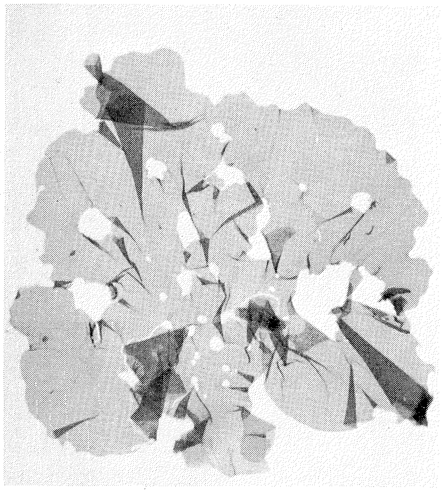

FIGURE 17. The membranous green laver, *Ulva latissima* L., a common and widespread plant in the lower intertidal and upper subtidal regions. (× ¼).

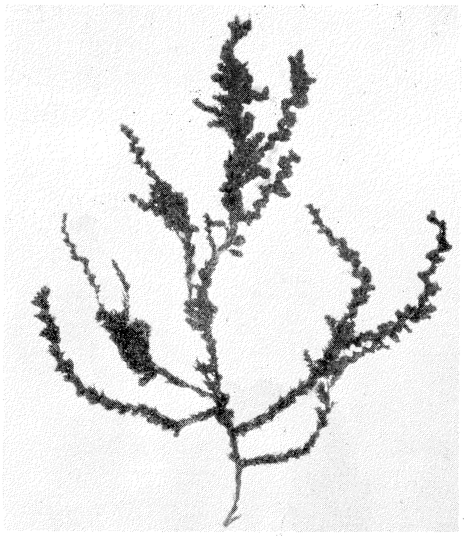

FIGURE 18. The red alga *Rhodomela larix* (Turn.) C. Ag., a common and widespread plant of the intertidal region. (× ⅓).

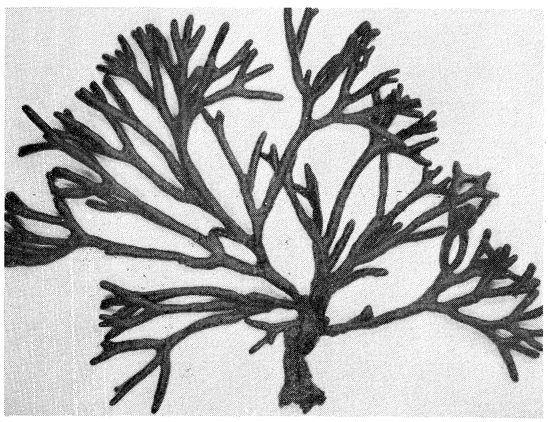

FIGURE 19. The green alga *Codium fragile* (Sur.) Hariot, a plant especially common in the lower intertidal region of more exposed regions. (× ⅓).

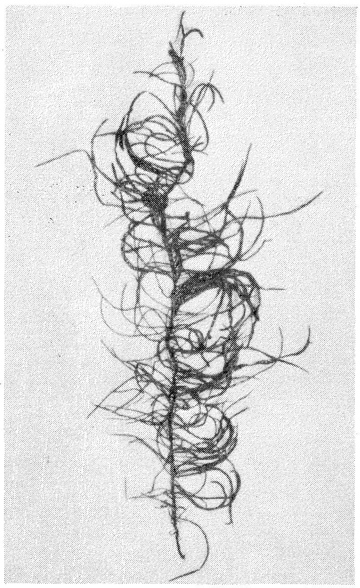

FIGURE 20. The brown alga *Heterochordaria abietina* (Rupr.) S. & G., a common intertidal plant. (× ⅓).

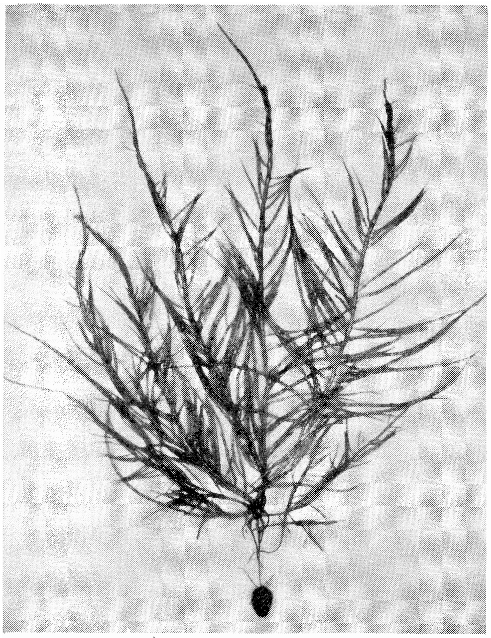

FIGURE 21. The red alga *Agardhiella coulteri* (Harv.) Setch., a common plant of the lower intertidal and subtidal regions. ($\times \frac{1}{3}$).

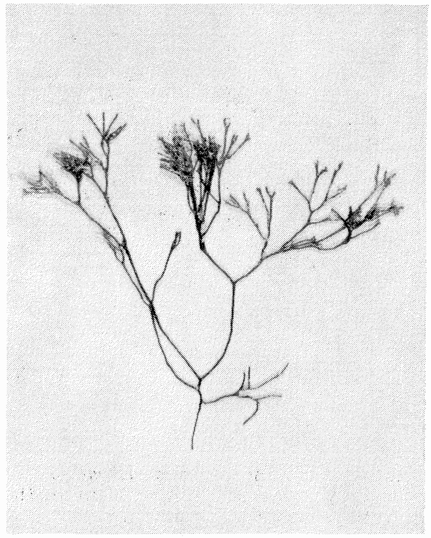

FIGURE 22. The agarophyte *Ahnfeltia plicata* (Hudson) Fries occurs in greatest abundance in more exposed regions of the coast. ($\times \frac{1}{2}$).

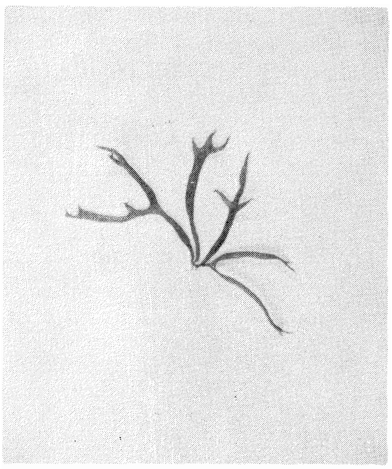

FIGURE 23. The red alga *Gloiopeltis furcata* (P. & R.) J. Ag., a common plant in the upper intertidal region on the exposed coast. ($\times \frac{1}{2}$).

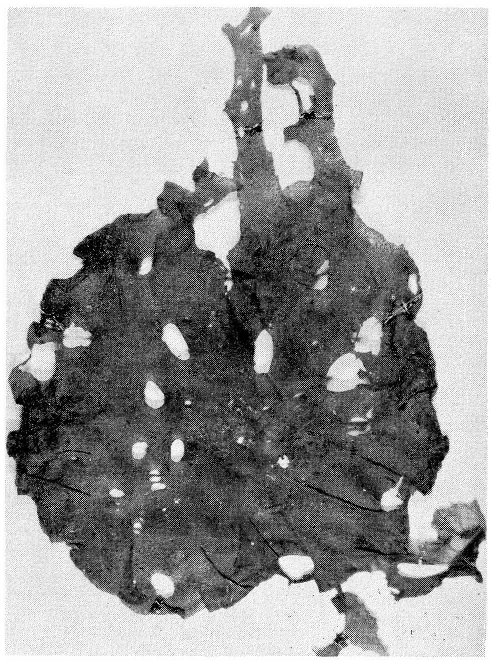

FIGURE 24. The red alga *Iridaea heterocarpa* P. & R., a common plant of the lower intertidal and subtidal regions. ($\times \frac{1}{2}$).

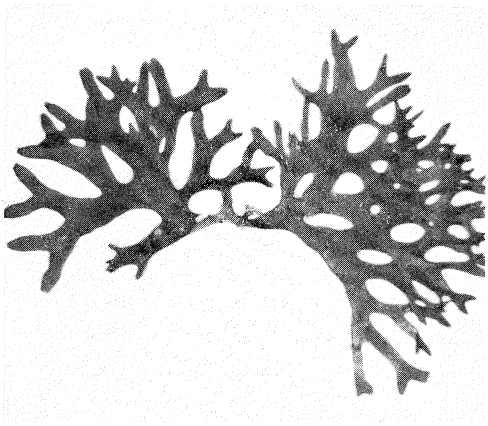

FIGURE 25. The red alga *Rhodoglossum affine* (Harvey) Kylin, a common plant in the lower intertidal region of the open exposed coast. (× ½).

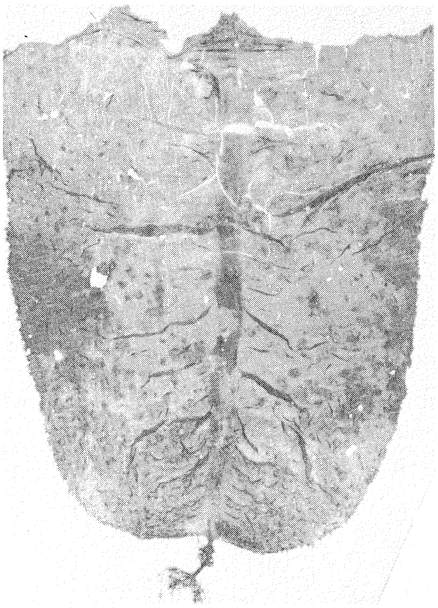

FIGURE 26. The kelp *Agarum fimbriatum* Harvey, a common subtidal alga. (× ½).

FIGURE 27. The duise *Rhodymenia palmata* (L.) Grev., a common plant in the lower intertidal and subtidal regions. (× ⅓).

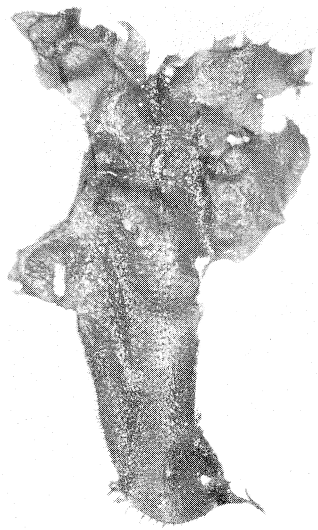

FIGURE 28. The red alga *Gigartina latissima* (Harvey) Eaton, a common intertidal plant. (× ¼).

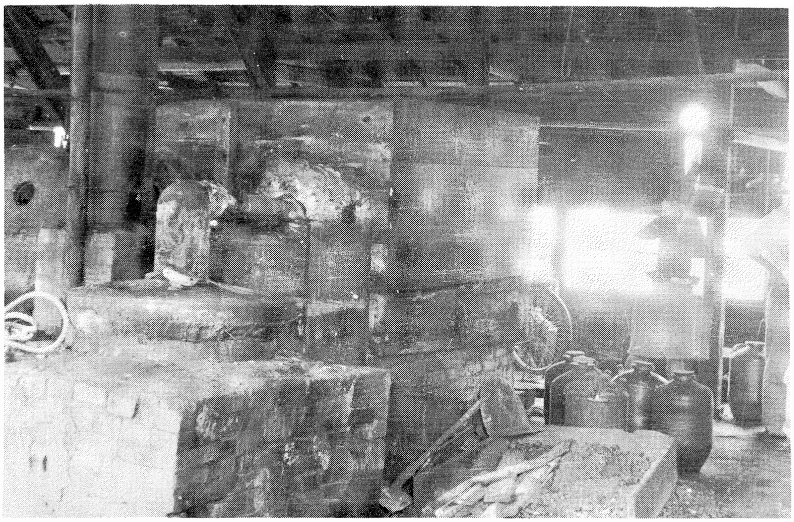

FIGURE 29. Still for subliming elemental iodine from seaweed in a small coastal seaweed products plant in Japan, 1946.

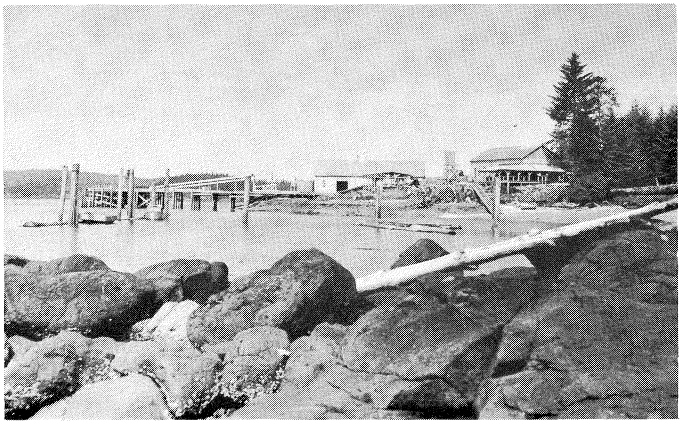

FIGURE 30. Wharf and processing plant of Canada Kelp Company Limited, on Deer Island, near Hardy Bay, British Columbia, in 1947.

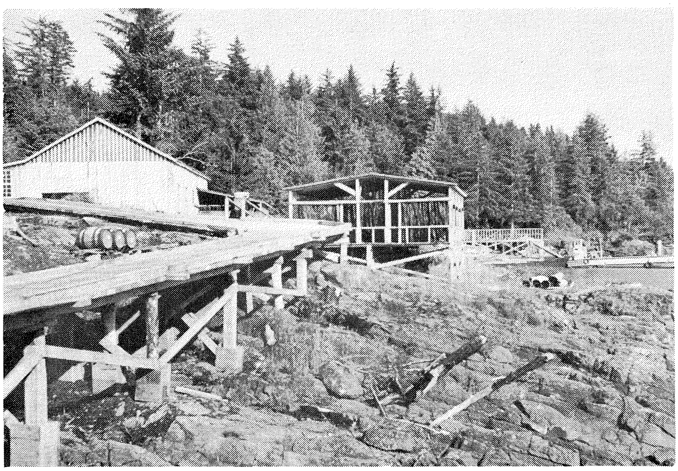

FIGURE 31. Powerhouse and pilot plant of the same plant as Fig. 30, showing outdoor drying racks and (right background) the converted landing-barge used as a harvester.

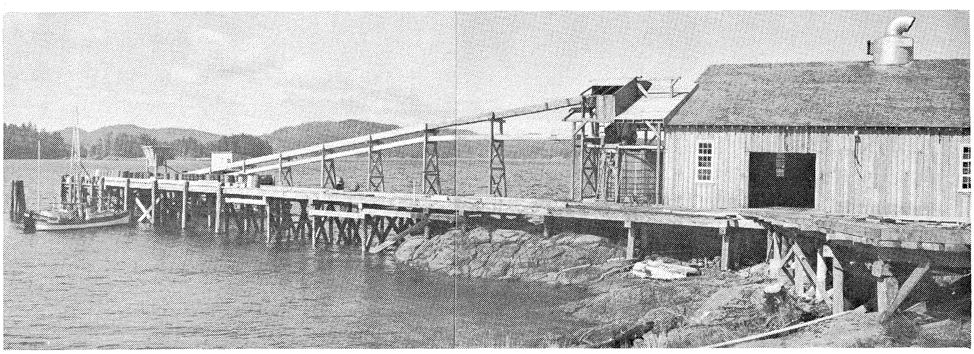

FIGURE 32. Wharf and processing plant of the same plant as Fig. 30. Kelp was chopped and placed in the hopper at the end of the wharf, then brought up the conveyor to a disintegrator and storage tank, where kelp pulp was held until transferred into the plant for further processing or drying.

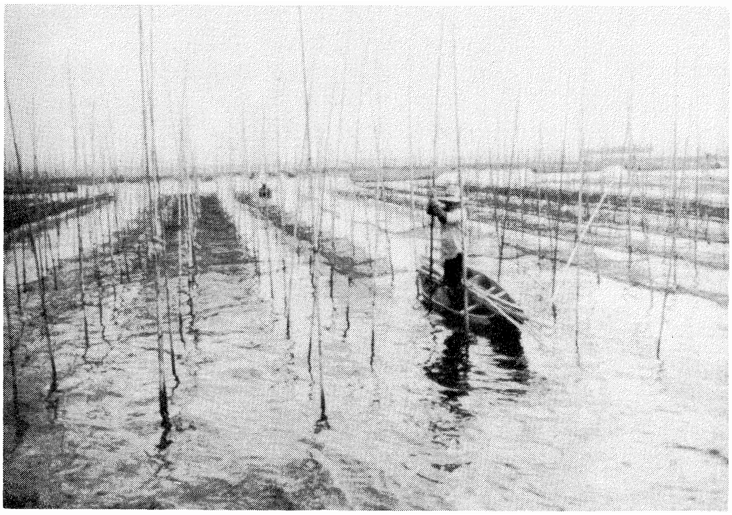

FIGURE 33. Japanese workman in Tokyo Bay inserting bamboo poles on which netting is supported for cultivation of *Porphyra*. Picture is at low tide at which time the nets are emergent.

the equipment in certain fish reduction plants might possibly be utilized. The growth of kelp and seaweeds in general is seasonal to some extent, and moreover, the maximum content of their various desired constitiuents may vary with age of the plants as well as other factors (Wort, 1955). These facts would all have to be considered in planning the harvesting and in arranging facilities for processing. There is need for considerable biological as well as technological knowledge for the successful establishment of an industry.

Effect on Fish

There has been some discussion whether the harvesting of kelp has any effect on commercial and sport fisheries. Would utilization of large quantities of seaweeds around the coast have some upsetting effect on the equilibrium in the cycles of sea life?

Many forms of animals, including fish, are found among the masses of seaweed, particularly among the branches of holdfasts. Some of these animals may not eat any of the plant material, but use such a location only as a means of protection from other animals, for the protection of their young or for a location in which to deposit or to fasten their eggs. The effect of removal of such plant growth on our fish or other marine animals should be considered. Removal of large amounts of seaweeds may well have an indirect if not a direct bearing on the protection and food supply of certain populations of marine animals. In Japan it has been stated that disappearance of seaweeds in certain areas has injuriously affected the abalone fishery.

How marine animals are supported has long been a problem for thought and investigation. Apparently those commonly seen are carnivores—consuming other animals. It must be true, however, that in the sea as on the land herbivorous animals greatly exceed in number and bulk the animals which feed upon them. Some of the larger forms of seaweed may form part of the food of some marine animals. Snails, many other molluscs, crabs and other crustaceans, and echinoderms such as sea-urchins eat parts of seaweeds—in fact many of the holes in the larger plants are a result of this activity. Parts of brown, red and green seaweeds have been found in the stomachs of sea cucumbers, chitons, urchins, squid and fish, and very complete digestion is sometimes possible.

Effect on Navigation

Kelp beds on the coast of British Columbia at most times of the year provide a valuable aid in disclosing the position of rocks and reefs in difficultly navigable areas. As the coast becomes more carefully charted, this use of kelp *in situ* becomes less important. On the other hand, in some areas harvesting of the kelp beds might aid certain types of navigation, particularly for fishermen, providing the harvesting did not interfere with the habitat of the fish.

Thus there are many aspects which need to be explored carefully before a large seaweed industry could be established on a satisfactory basis.

USES OF MARINE ALGAE

HISTORY

Utilization of seaweed in the Orient was probably far earlier than any use in the western world. At a time when the early Greeks and Romans apparently held marine plants in low regard, the Chinese and Japanese had already for some centuries used many of the larger kinds as food. Seaweeds have been considered of medicinal value in the Orient since the time of Shen Nung, the father of husbandry and medicine, who lived about 3000 B.C. In the Chinese classic "Book of Poetry", written during the time of Confucius about 550–480 B.C., there is mention of seaweed having being cooked as food by a housewife. However, the value of Irish moss as a food, and of kelps and rockweed as fertilizer, became known in Europe long before trade with the Orient began.

The Japanese are said to have learned of seaweed uses from the Chinese, but the production of agar apparently had its origin in Japan, and it was introduced from there to the western world. According to legend a Japanese emperor and party were marooned in a snowstorm while travelling in the mountains, and accepted the hospitality of a peasant family. An abundance of seaweed jelly was prepared and that which remained after the meal was discarded. The discarded jelly lay upon a shrub where it froze during the night. Immediately after came a thaw, and the peasant was surprised to find the frozen jelly collapsed; the water part had flowed away, and the remainder shrunk to a glistening, paper-light mass—this was crude agar. This peasant found that the dried jelly could be restored to dessert form, as good as the original, if it were merely heated again with water and then cooled. In this way, according to the legend, the agar industry arose in Japan.

The operations in Japan today for the extraction and preparation of crude agar are much like those recorded in this legend. Agar was the first seaweed product to become an important stable item of commerce and is still produced in great quantities in Japan. At first it appeared as a novelty dish, later it acquired a variety of uses, but became of greatest importance to bacteriology and microbiology as a solidifying agent for culture media and in medicines. During the second World War agar-producing plants were established on the Atlantic and Pacific Coasts of the United States and on the coasts of Australia and New Zealand.

Until the end of the 18th century, vermifuges made from two species of *Corallina* (*C. officinalis* and *C. rubens*) were popular, but these were abandoned in favour of Corsican moss (*Alsidium helminthochorton*, sometimes adulterated with *Laurencia obtusa*) when the latter was discovered by Stephanopoli, a Greek doctor, in 1775. *Codium fragile* has also been used as a vermifuge for *Ascaris lumbricoides.*

Marine algae were used on farms in Norway as fodder and fertilizers at least as far back as the 12th century, and even at that time regulations were in effect relating to the collection of algae. As food for man in Europe, however, seaweeds have generally been used only locally, or in times of extreme want.

Industrial use of seaweeds in Europe began during the first half of the 17th century. From about 1720, algae were burned for the extraction of carbonate of soda, used in the manufacture of glass and soap. Some believe that the first use of the term *kelp* was with reference to the fused hard cake resulting from the burning of seaweeds. "Soude" or soda was the name given to the ashes of burned seaweeds which were used in glass and porcelain works in Normandy. Some of the largest kelp soda industries were in the Shetland Islands, the Orkney Islands and the Hebrides. Although this was an expensive method (yielding only about 4% soda), for nearly a century seaweed ash was the chief source of this alkali. Eventually Leblanc found a far cheaper method of producing soda, from salt. Kelp-burning as an industry subsequently declined and in many places it ceased entirely.

In 1811 the French chemist Curtois discovered in seaweed ash the element iodine, which was soon widely used in medical operations as an antiseptic, and later in dyestuffs and in photography. Kelp burning was resumed and again provided a steady income for coastal populations in various countries of Europe. Although iodine is one of the scarce non-metallic elements in the sea, it is accumulated by many marine algae. Some species, notably *Laminaria digitata*, called tangle, contain a very high concentration of iodine in the form of iodides. In some instances seaweeds have been found to contain 10,000 to 20,000 times the concentration of iodine present in sea water, and deeper-water plants frequently possess more than those growing in shallow water. Natural sea water contains only 0.01 to 0.07 part per million of iodine. Eventually, with the discovery of cheaper sources of iodine, this industry too died out in Europe, although it persists to some extent in Japan (Fig. 29). To-day some iodine is recovered from brine in California, but the main source is from iodate occurring in the nitrate deposits of Chile. These deposits are doubtless of marine origin.

During the recent war *bromine* was extracted from *Rhodomela larix* (Fig. 18) in Hokkaido, Japan.

The use of Irish moss gel, carrageenin, was discovered first in Ireland. The earliest use of carrageenin, which was obtained crudely from *Chondrus crispus* (Irish moss), was as a gelling agent for desserts such as blancmange and puddings. The Irish moss industry on the American continent began over 100 years ago on the Atlantic coast and still thrives.

Although seaweeds have been used for fertilizer for many years in a number of countries, including England and Ireland, it was only at the onset of the first World War that commercial fertilizer was produced on a significant scale from seaweeds. When the supply of potash to North America from European mines became greatly reduced, this element was obtained from the kelp beds of the Pacific Coast particularly. The United States Department of Agriculture between 1911 and 1913, and the Fisheries Research Board of Canada in 1914, had made extensive surveys on the Pacific Coast to evaluate the available seaweed resources. Although these beds provided a valuable supply of seaweeds, actual harvesting proved that many of the yield estimates could not be realized. Again, with the discovery and mining of new deposits of potash in the United States and in South America, seaweeds soon gave way to cheaper sources of fertilizer.

In England the nature and value of algin were discovered by Stanford in 1884 while he was engaged in the Scottish kelp industry. He noted that large blisters formed on kelps after they were exposed to rain and that these blisters, when cut open, exuded a colourless viscous substance which he found was insoluble in water but very soluble in alkali. Although it is now thought by some that these blisters probably contain laminarin and not algin, Stanford's observation led to the discovery of algin. He later found that algin contained calcium, magnesium and sodium in combination with a newly identified acid, called alginic acid. On further study, numerous interesting properties were discovered when this acid was combined with different salts to form various alginates. Although the uses to which alginic acid could be put were not fully recognized for many years, more recently the interest in the raw materials obtainable from marine algae has been again revived. This is principally because a number of the organic compounds obtainable from seaweeds have been found to have extensive application in industry. These substances are complex polysaccharides, generally known as phycocolloids, and are able to form colloidal systems when dispersed in water. The ones most used to-day are algin, agar and carrageenin.

The slimy phycocolloids occur for the most part as cell-wall constituents, corresponding to the cellulose in land plants, and are extracted on a commercial scale only from the brown and red algae. These marine plants have a very distant relationship at best to the green land plants, and their phycocolloids reveal properties which, for the most part, do not occur in land plants. There are important differences between the gums and mucilages of land plants and the seaweed phycocolloids, although superficially they do resemble one another. In particular, these colloids can form viscous solutions in water, and can retain their water, properties which are important for aquatic plants subject to exposure and drying in the intertidal zone.

Among the most important phycocolloids now being extracted on a large scale, are alginic acid, which is obtained from certain brown algae, and agar and carrageenin, which are obtained from certain red algae. In addition to these slimy compounds there are certain other cell-wall constituents, such as fucoidin, and cell-content substances of a reserve nature, such as laminarin and mannitol, which have at present no great economic significance.

Thus the seaweed industry has had several periods of prosperity: first, as a source of soda ash; secondly, as a source of iodine; thirdly, as a source of potash; and finally, as a source of organic constituents. Each of the earlier periods of exploitation, involving inorganic chemicals, has given way almost completely following discovery of a superior method of making these products. At present then, the seaweed industry thrives largely as a source of organic products.

The seaweed industries of the past have flourished mainly during periods of war and shortage when international trade relations have been hindered or disturbed. In fact, it even took the second World War and the cutting off of the supply of agar from Japan to really give the stimulus to agar production in the United States, New Zealand and in other countries. Today, organic seaweed commodities have gradually found a natural and permanent place in the world economy, and some of them offer still greater possibilities of usefulness.

Particularly since the second World War the seaweed industry has had a rapid and extensive development and there are many indications that it will continue. The price of agar, for example, has more than trebled since 1928, and even so the supply can scarcely keep up with the demand. In 1948 the production of the three most important seaweed colloids in the United States (agar, carrageenin and algin) reached more than 3,000,000 pounds, valued at more than $5,000,000; and in 1959 the value of the seaweed colloids was about $10,000,000.

ALGAE AS FOOD

In general, seaweeds in their natural form provide a poor source of food for man because much of the plant material is indigestible and too high in inorganic substances. There are no poisonous species known. The energy-yielding food constituents of seaweed consist chiefly of carbohydrates and some fats and proteins. Carbohydrate usually constitutes from 17 to 60% of the dry weight, protein usually not more than 6 to 29%, and fat less than 4%. However, since most of their complex carbohydrates cannot be digested by man, seaweeds are considered a poor source of energy. The amount of ash varies from 25 to 35%, although this changes greatly with different algae and at different times of the year. The nutritional value of seaweeds lies in their vitamins and mineral content. The antiscorbutic vitamin C content of some seaweeds has been shown to equal or exceed that in lemons and the proportion of vitamin B_1 (thiamin) compares favourably with that in many fruits and vegetables.

Phytoplankton, on the other hand, shows somewhat more fat or oil, reaching 7% of dry weight, and vitamins A and D are present in fair quantities. Collection problems (e.g. filtering) and possible irritant effects of cell walls, such as the siliceous material of diatoms, have so far largely discouraged the harvesting and using of plankton forms as a direct source of human food.

Few domesticated animals like seaweed unless raised on a diet containing them. When seaweed is mixed in small quantities with other feed for stock, there seems to be some apparent benefit, but more nutritional studies are needed to determine the exact nature of these benefits and the efficiency of utilization. Owing to its high content of mineral salts, seaweed meal is not generally suitable to be used as the only food material for animals. It is frequently mixed 2 to 5% with other feedstuffs. In preparing seaweed meal it is frequently necessary to remove various undesirable salts which have a laxative effect, by treating the seaweed with hot water or cooking it to leach out these salts. Some have claimed that up to 30% seaweed (*Fucus*) could be included in the ration of pigs, sheep and cattle. It is said to impart gloss to the coat of fur-bearing animals and create a healthy skin. In some cases, however, iodine had to be removed to prevent iodine poisoning.

In Europe, particularly in Norway, Scotland and Ireland, cattle and goats graze on seaweeds at low tide—particularly on *Fucus* (bladder-wrack), *Rhodymenia*, *Chondrus* and *Alaria esculenta*. There is an industry in Norway which processes seaweeds for feeding stock. Horses, pigs and cattle in these countries are fed a mixture of these algae with other feeds. Deer and cattle have been observed feeding on seaweeds along the coast of British Columbia at low tide, although their salt content may be the principal attraction. Some experiments with fowl have shown that seaweed is of questionable value in their diet, at least in high concentration, and frequently causes diarrhea. There are contradictory statements in the literature on the value of seaweed meal for poultry and stock feed.

The carbohydrate material present in seaweeds is better utilized by some animals than others. Nutritional utilization of agar by man is very incomplete. Dogs, and especially ruminants, digest agar more completely. In some instances algin may be nearly 50% digested.

Of the three commonest seaweed products—agar, carrageenin and algin—algin is the most digestible and agar the least. The real value of agar is not the actual nutritive value but rather in its ability to serve as a solidifying, suspending, stabilizing and bulk-providing agent. Agar sets to a rigid gel at warm temperatures—even in the tropics—and does so more rapidly and at lower concentrations than gelatin. The latter is subject to bacterial action, whereas agar by itself is relatively inert to most bacteria and is hardly attacked at all by plant enzymes or animal digestive juices.

Vitamin A is not an important constituent of seaweeds, but species of *Fucus* (Fig. 15) and some other algae have been shown to contain beta-carotene, which is closely related to vitamin A. Some species of *Laminaria* also contain vitamin B_2 (riboflavin) in appreciable amounts. Vitamin D is present in very small amounts, or absent. Algae growing in the upper intertidal zone or on the surface usually tend to have a higher content of vitamin C than those at a depth of 5 to 10 fathoms. *Porphyra* (Fig. 16) and *Ulva* (Fig. 17), for example, are reported to be rich sources of vitamins B and C, as are some species of *Rhodymenia*, *Gigartina*, *Laminaria*, *Fucus* and *Alaria*.

As a good source of iodine, which is required for the normal functioning of the thyroid gland, seaweeds can aid in preventing or alleviating goitre. The fact that goitre and other diseases of the thyroid are practically unknown in the peoples of Japan and China is thought to be a result of their use of a large amount of seaweed in the diet. Some South American peoples chew *palo coto* or goitre stick—pieces of the stipes from certain seaweeds, probably *Laminaria*.

Seaweeds also contain bromine, calcium, magnesium, sodium and potassium salts in considerable quantity.

In the British Isles, Norway and the United States, and for a brief period in British Columbia, as well as elsewhere, food supplements have been prepared from seaweeds, particularly from *Laminaria*, *Fucus* and *Macrocystis*. A kelp company, which was in operation at Deer Island near Port Hardy in British

Columbia between 1946 and 1948 (Fig. 30–32), produced a small amount of dried seaweed from *Macrocystis integrifolia* as kelp meal and in the form of pills as a health food. Although this company proposed to expand into the production of algin, it experienced financial difficulties which forced its closure before the potential of the area was technically realized. In 1960 dried kelp meal imported from Norway was available on the market in Vancouver, selling at about $8 per 100-pound bag.

Kelp meal and kelp salts are still being produced commercially in the United States on a relatively small scale as "health foods" and dehydrated kelp tablets as a nutritional supplement. Although remarkable powers and "added" curative substances have been claimed for some of these, in most instances the products appear to be unadulterated dried seaweed. The seaweed is usually powdered or compressed into tablet form when sold to the customer.

The use of algae in the human diet goes back into antiquity and seaweeds are still eaten and regarded as delicacies in a number of countries. This is particularly true in countries bordering the western shore of the Pacific Ocean, and the Indian Ocean generally. However, in an untreated state many of the seaweeds are not palatable, which led Harvey (1851) to remark that "though the skill of the cook can readily impart an agreeable flavour to a tasteless substance, it is more difficult to overcome the smack of an unsavoury one."

Among the species of seaweeds that have been and are eaten in various parts of the world, the following genera occur in British Columbia, as either the same species or a closely related one: *Enteromorpha*, *Ulva* (Fig. 17), *Dilsea*, *Monostroma*, *Codium* (Fig. 19,) *Grateloupia*, *Heterochordaria* (Fig. 20), *Mesogloia*, *Fucus*, *Chaetomorpha*, *Scytosiphon*, *Petalonia*, *Agardhiella* (Fig. 21), *Laminaria*, *Pelvetia*, *Pelvetiopsis*, *Bangia*, *Porphyra*, *Ahnfeltia* (Fig. 22), *Gelidium*, *Gloiopeltis* (Fig. 23), *Gracilaria*, *Iridaea* (Fig. 24), *Rhodoglossum* (Fig. 25), *Ceramium*, *Alaria*, *Costaria* and *Sargassum*. A number of common names are applied to certain better-known groups of these. *Nori*, which means "paste", is the general name in Japan for edible seaweeds of all types, including the cultivated *Porphyra*. Species of the kelps or Laminariales, except for *Alaria*, have been known as a food since 1730 by the name *kombu*. Among these, species of *Laminaria* and *Agarum* (Fig. 26) are used as food in a variety of ways by the Japanese, but the bulk of the kombu production is still exported to China. In 1894 over 41 million pounds were shipped. The value of the kombu industry to the Japanese fishermen at present comprises almost one-third that of the nori (*Porphyra*) industry and is centered in Hokkaido. In harvesting kelps for kombu, the Japanese gather the seaweed in open boats, then the plants are spread on the beach to dry. When most of the moisture has evaporated the seaweed is trimmed and packed in long flat bundles and shipped to a manufacturer. It is frequently dried and pressed into compact blocks. When required for food the blocks are sliced with a sharp knife, then soaked in fresh water and boiled. Kombu is cooked with meats, powdered and used in soups or with rice and sauces, served as a vegetable, steeped as a drink or coated with sugar and eaten as a confection.

Alaria species are known in Japan as *sarumen; Petalonia* as *habanori; Undaria* as *wakame*, *Ulva* as *aosa; Enteromorpha* as *awonori; Codium* as *miru; Gloiopeltis* as *funori; Iridaea* and *Rhodoglossum* as *ginnanso; Mesogloia* as *mozuku.* Although the term *nori* strictly speaking refers to all types of seaweeds, it has now come to be synonymous with prepared *Porphyra*, the most popular of the seaweed preparations in the Japanese diet. *Porphyra* was formerly known as *hoshinori* or *amanori* and the prepared product as *asakusanori.* Asakusanori refers to the fact that the first place where *Porphyra* was grown commercially and collected was near Asakusa, or old Tokyo. *Ahnfeltia* and *Gelidium* are known as *kanten* (*tungfen* of the Chinese), *Gelidium corneum* as *tengusa*, and *Heterochordaria* as *matsumo. Grateloupia filicina* (*mukadenori*) is dried and eaten with vinegar and soy sauce. *Alaria* species (*kausam*), *Porphyra* (*nuru*), *Fucus* (*messkunum*) and *Halosaccion* (*kushuchich*) are used as food in Kamchatka.

The uses of these different algae are varied. *Enteromorpha* and *Ulva* are used as a garnish (dried or powdered) much like parsley in meats, fish and salads, or as a table decoration. The Japanese also use the red alga *Gracilaria* (*ogonori*) as a garnishment after treating it with hot water or with limewater to turn it green. They use *Laurencia*, commonly called pepper-weed, as a hot condiment in conjunction with other foods. Many algae are used in soup stocks, in jellies, or as vegetables. In Japan fresh *Heterochordaria* is packed in salt, sometimes together with mushrooms, and later cooked with soy sauce. *Mesogloia* is preserved in salt and eaten with vinegar as a salad. Others, such as the murlins (*Alaria*) or *Codium*, are eaten like spinach. In several European countries *Alaria esculenta* (*badderlocks* of Scotland, *murlins* of Ireland, or *henware*) have been eaten and *Dilsea edulis* is used like dulse. Some species of *Laminaria*, often called *sugar wrack* because of their sweet taste, have been eaten in Europe. They owe their sweet taste to the presence of mannitol. Because seaweeds produce little heat when digested and assimilated by the body they are recommended as hot-weather foods for those who do little manual work. A bread made from a mixture of wheat flour and seaweed meal has been manufactured in northern Europe.

Although many of these uses for seaweed in the human diet are relatively limited and local in nature, there are fairly large industries based on a few of the plants that are used directly as food.

Perhaps the most interesting of these industries, and undoubtedly the most ancient, is based on the *purple laver* (species of *Porphyra*) which in Japan comprises an important part of the nori industry, and on the Laminariaceae used for the kombu industry already mentioned. Although *Porphyra*, which is also known as *laver bread*, *marine sauce*, *sloke*, *slack*, *slouk* and *sloucawn* has been and is still being used in a number of countries in Europe, in Hawaii and elsewhere, it is only in Japan that it has become the basis of a thriving industry. The culture of *Porphyra* seems to have been the only significant attempt at cultivating marine algae on a commercial scale, although the Japanese have also sunk rocks in the water in certain regions to promote the growth of beds of *Laminaria* and have cultivated *Gracilaria* to a less extent. *Phyllospadix* has also been removed from some northern parts of Japan to permit *Laminaria* to cover certain areas.

Since 1670 *Porphyra* has been "farmed" in Tokyo Bay and elsewhere in Japan (Fig. 33). The principal species used is *Porphyra tenera*, although for the last few years *Porphyra yezoensis* from Hokkaido has been introduced to a number of the cultivation areas in Honshu. As early as 1901 in Japan there were 2,242 acres of sea floor in cultivation producing about 4,769,000 pounds of dry seaweed, and by 1951 more than 12,000 acres of sea floor were known to be in cultivation and the product for the latter year was valued at about $6,000,000. In the Tokyo region in 1901, there were 951 acres under cultivation and 3,493 families of fishermen were engaged in the occupation. In 1957 some 476 corporations having about 300,000 employees were engaged in the Japanese industry, and in Tokyo Prefecture alone, which includes only part of Tokyo Bay, there were about 2,000 acres under cultivation. More than four times this area was under cultivation in 1957 in other parts of Tokyo Bay. The value of this industry to the Japanese fishermen in recent years is over $17,000,000 annually. The plants are harvested by hand, made into sheets and dried. The product is used particularly in the preparation of Japanese macaroni, in soups and sauces, and for wrapping around pieces of fish or meat rolled in rice as a sandwich (*sushi*). In European countries it is boiled for several hours and served as a semi-fluid mass or sometimes it is eaten with lemon juice or vinegar.

The original method of cultivation used by the Japanese was to set out bundles of bamboo poles in shallow water on sheltered shores. The reproductive structures of *Porphyra*, which are carried about in the water, settled on these and matured. The mature plants, which remained fastened to the bamboo poles, were later harvested. In some areas artificial concrete reefs have been made in order to support further growth of *Porphyra*. This older method, using bamboo bundles, has now been almost completely replaced by a system of suspended nets made of coconut fiber. In some regions concrete has been used to cover a rough rocky area in order to provide an easier substratum from which to scrape the seaweed during harvesting. In some parts of Japan as many as 7 harvests a year can be obtained.

The Indians of the Pacific Coast make a somewhat similar use of certain local species of *Porphyra* which they collect along the rocks, usually in early summer. They also eat the native species of sea lettuce or green laver (*Ulva*). This habit of using seaweed as food is believed responsible for contributing to the low incidence of goitre among coastal Indian tribes. In the past some of the North American Indians did not believe in using salt, from which they would normally obtain iodine necessary for proper functioning of the thyroid gland. The Indian believed the use of salt would make him prematurely gray like some of the white men, and cause an early death. The Iroquois, who sometimes ate people, referred to the white man as a salty one in contrast to the red man (Chase, 1942).

Rhodymenia palmata (Fig. 27), commonly known as *dulse* or *dillsk*, has been widely used, especially in Ireland, Scotland, the Maritime Provinces of Canada, and New England. In many parts of the world it is used as a food, a relish or medicine. It is eaten raw, fried, cooked with soups, chewed like gum, eaten with fish and butter, as relish with potatoes, or boiled with milk to which rye flour has been added. According to some, chewing dulse is like eating peanuts: once started it is hard to stop.

At the time when famine was widespread in Ireland, dulse and potatoes formed the staple foods for the people along the coasts. It is used in many parts of the United States. Some is gathered in New England, but most of it is imported from the Maritime Provinces to the market in the United States. Dulse is still gathered and used as a relish by the Indians in the Pacific Northwest or cooked with other foods, including boiled fish. It is also used as a vegetable on the Atlantic Coast where it is called *sea kale*.

There is a variety of uses of algae that can be recorded in connection with human activities. *Rhodymenia palmata* is used in Kamchatka to prepare a strong alcoholic drink. The Alaskan Indians and Eskimos are reported to make a brew called *hoochenoo* from *Nereocystis*. Methods have been proposed for the manufacture of manna-like substances from certain species of *Laminaria* containing a considerable amount of sugar and mannitol. A candied peel and pickles have been prepared from the fleshy stipe of *Nereocystis*.

An indirect use is of interest in fish-culture programs in the Philippines and elsewhere in the Pacific area where a herring-like fish called the milkfish or bandeng (*Chanos chanos*) is raised commercially. Frequently species of *Cladophora* and *Chaetomorpha*, as well as other small green algae are used to feed the young fish during early stages of development. Then later, when the fish are older, they are fed *Enteromorpha* species. In 1952 about 200,000 acres of ponds in Java alone produced 33 million pounds of fish in a year and provided a living for 250,000 people in activities related to the industry.

An interesting use of Pacific Coast kelp meal was made by Wales (1944) who found that a deficiency disease in artificially reared trout which were fed beef liver could be cured by feeding kelp meal. The kelp meal supplied certain minerals normally obtained from fish in the natural diet.

AGAR

Agar is an abbreviation for the Malayan or Ceylonese term *agar-agar*, which means jelly. It is produced exclusively from seaweeds and has been known in Japan as *kanten* since 1760. Sometimes it is referred to as gelose. Some species of *Gracilaria* have been known by the name *Ceylon moss*. The agar industry is based on various species of red algae, largely *Gelidium*, *Ahnfeltia*, *Ceramium* and *Gracilaria*, although to some extent on *Eucheuma*, *Halosaccion*, *Endocladia* and *Iridaea*. Sometimes various mixtures of these agarophytes are used by the Japanese to obtain certain desirable properties. *Agardhiella*, *Gigartina* (Fig. 28) and *Gloiopeltis* produce gels that are less rigid than agar, more like carrageenin, and are frequently referred to as agaroids rather than agarophytes. The major hydrocolloids in the red algae are polymers of galactose. Agar is a neutral polymer which has low viscosity in water solution, a sharp stable gelling temperature and a strong gel structure. Most of the agarophytes are obtained from naturally recurring beds, although the Japanese have propagated *Gracilaria* in Tokyo Bay with some success. Branches of the plant are placed in the twist of ropes at intervals and the ropes are suspended in nutrient rich waters. The propagation of *Gracilaria* also has been aided in certain areas in Japan by scattering shells, stones and other solid materials over a smooth bottom.

The chief method of collection of agarophytes is by hand, although special rakes and diving suits are used to facilitate collection in deeper water. In California, divers collect *Gelidium* at depths from 10 to 50 feet. In certain areas on the Atlantic Coast large masses of *Gracilaria* are collected by towing a net or by raking into a skiff as the plants drift ashore across sandy or muddy flats.

Until the outbreak of the second World War, the Japanese dominated the market for agar. It had been imported into Europe since 1856 from the Orient. When an acute shortage threatened Britain and other countries an extensive program of exploration and research in an attempt to produce agar from local seaweeds began. Since the War many countries, including Britain, Denmark, Australia, the United States (both coasts), U.S.S.R., New Zealand, India and South Africa, have made themselves largely independent of imports. In some countries there is now enough produced from local red algae for local requirements and some for export.

Although it has many of the physical properties and uses of animal gelatin, the chemical nature of agar is quite different and it has many special uses for which gelatin is not suited. The production of agar is not complicated, but it requires considerable technical knowledge and involves careful purification of the end product for specialized uses.

The amount of agar present varies with the species, as well as the season. Most of the more commonly used species contain from 30 to 35% agar on a dry-weight basis, although *Ahnfeltia* and other species sometimes run to 50%.

The uses to which the manufactured products are put are varied and numerous. In addition to its use in media for bacteriological cultures, agar is used in medicine in a variety of ways. It is a useful therapeutic agent in intestinal disorders since it is a non-irritant bulk producer having the property of absorbing and holding water and at the same time acting as a mild laxative. In this way it is more effective than carrageenin which loses part of this bulk-producing effect because it is partially digestible. Agar is used to make capsules to enclose antibiotics, sulpha compounds, vitamins and other substances when a slow release of the medicant is desired at a point beyond the stomach. An ancient Polynesian practice of using certain filamentous algae for poultices for sore eyes, cuts, bruises, sores and boils now has a modern version in that a preparation of agar is sometimes used with considerable success beneath bandages or surgical dressings for healing certain types of wounds.

The elasticity of agar permits the making of certain types of dental impressions, although for this use it has now been replaced to a considerable extent by algin compounds.

Agar has additional uses in microtechnique in hospitals and laboratories. It is used in the photographic industry for emulsions on film backings and plates. In the manufacture of storage batteries and hectograph duplicators, and as a binder in toothpaste and in some pastes, agar is used extensively.

Certain special breads for diabetics have the starch replaced by agar. Tobacco and fruit cakes sometimes contain added agar to control moisture and prevent drying out. Agar is added to icings and marshmallows to prevent stickiness or adherence to wrappings during damp weather. It is used in cream cheese to improve the texture and in other cheeses to improve slicing.

In the preparation of canned fish, poultry, pickled tongue and some soft foods, agar produces a better packing medium than gelatin because it does not melt at as low a temperature, and thus prevents breakage of the food.

Agar is widely used as a stabilizer, as a thickener and body-producer, and as an emulsifying agent in soups. It is used in pie-fillings, meringues, sherbets, candies, chocolate bars, various jelly desserts, salads, puddings, mayonnaise, jams and preserves.

Dried agar, carrageenin and algin have many uses in common. They have individual properties which restrict or enhance their use depending on the circumstance. Although, for example, both agar and algin are used in ice cream as a stabilizer, it takes less algin than agar to do the same job.

CARRAGEENIN

Carrageenin, a gelatinous extract obtained commercially from *Chondrus crispus* (commonly known as Irish moss) and some species of *Gigartina*, gets its name from a village in Ireland near Waterford called Carragheen, where its use was first of significant importance. Other spellings are carrageenan, carragheenin, carrageen, carragheen, and carrigeen. A substance rather similar to carrageenin is obtained from *Grateloupia filicina*.

The presence and use of *Chondrus* on the North American Atlantic Coast was first drawn to the attention of commerce in 1835 in Massachusetts. It is now harvested commercially and raked up by farmers and fishermen in the off seasons in a number of places in Massachusetts, Maine, the Canadian Maritime Provinces and Newfoundland. In 1947 in Maine alone 1,643,607 pounds valued at $40,070 were harvested, and in 1946 in the Maritime Provinces 2,354,000 pounds were taken. The product from Prince Edward Island alone in this same year was valued at \$80,000. In 1957 in the Maritime Provinces 25,948,000 pounds valued at about \$335,000 were harvested with 15,274,000 pounds coming from Nova Scotia, 10,659,000 pounds from Prince Edward Island, and 15,000 pounds from New Brunswick. In 1960 the total gathered in the Maritime Provinces was 27,936,000 pounds. Most of it is still exported to the United States for processing

Most of the plant material is harvested by hand: usually collected by special rakes, from a dory. The plants are wedged between the tines of the rake and torn from the rocks on which they grow. It takes about four hours for a moss gatherer to fill a small dory with wet Irish moss.

The amount of carrageenin obtained from seaweeds varies with the species as well as the season, but at times may be up to 65–70% of the dry matter.

The uses to which the extracted material is put are almost as numerous and varied as those of agar. The hydrocolloids produced are strongly charged electrolytes with gelling temperatures dependent on the salts dissolved with them. They have high viscosities in water solution and possess an ability to alter the physical properties of various fluids. In addition carrageenin has thickening, emulsifying, stablizing and suspending properties. It was first used as a gelling agent for desserts, but now has many other uses in the food industry. It is used as a stabilizer in chocolate milk, cheeses, ice cream, sherbet, salad dressings, fruit syrups, flavourings, icings, pie-fillings, puddings, jellied poultry and fish, soups and confectionery.

Carrageenin is used in preparing emulsions, ointments and tablets in various pharmaceutical preparations. Insect sprays, water-base paints and inks frequently contain carrageenin. It is used to size paper, cloth and thread in the textile industry. Carrageenin is used in shoe stains, finishing leather and graining it, certain printing processes, cosmetics, and shampoos; as a coagulant and a dental impression compound; and in powdered form as a clarifying agent in the manufacture of beer.

ALGIN

Algin, or alginic acid, is produced exclusively from seaweeds and occurs in the plant as a cell-wall constituent. It is a salt of a polyuronic acid (mannuronic acid). The soluble salts (sodium, ammonium, potassium) of this polymer are generally referred to as algin. Any salt of this polymer is an alginate and organic salts or esters are called algin derivatives.

Although the peculiar properties of algin, including the gelling power, were recognized when algin was first discovered, it was not until after 1940 that the algin industry became of significance because of the war-time interest in alginates for non-flammable camouflage materials. Since then, valuable industries have developed in Britain and California, and to a limited extent in the Canadian Maritime Provinces and Australia.

Algin is obtained from kelps. Species of *Macrocystis*, *Laminaria*, *Nereocystis* and *Alaria* are particularly abundant in algin, but it is also present in *Egregia*, *Fucus*, *Hedophyllum* and many other brown algae. The quantity of algin present varies with the species, the part of the plant and the season. Some species contain nearly 50% algin on a dry-weight basis, although it generally runs between 15 and 30%. Over 90% of the plant material is usually water, and on a wet-weight basis about 4% is algin.

Although some kelp has been harvested by hand or collected as it is cast ashore in drift, various mechanical rakes, grapnels, and cutting machines resembling hay-mowing machines (for harvesting *Macrocystis*) are employed to harvest the bulk of the seaweed, which is subtidal. In some instances, for example *Nereocystis*, the bulk of the plant material floats near the surface, although the basal attachment is subtidal. Off the coast of California thousands of tons of kelp are harvested each year using giant underwater mowing machines that are operated from motor-driven barges. These barges can carry several hundred tons of fresh kelp. In British Columbia the rocky, indented coastline (Fig. 1) makes harvesting by mechanical methods more difficult than it is along the much smoother and straighter coastline of California.

Although alginic acid as such has only a limited use, its salts, the alginates, both in soluble and insoluble form, have a great variety of uses. Alginic acid itself can absorb 10 to 20 times its own weight of water, but when dried it becomes so hard that it can be turned on a lathe. In contrast to agar, alginic acid produces viscous or gummy sols with water instead of the firm agar-type gel. Being a weak acid, it forms a wide variety of alginates having interesting properties, as well as complex compounds of the plastic type. For example, ammonium alginate is used in fireproofing fabrics, calcium alginate in plastics and as a laundry starch substitute, sodium alginate as a stabilizer in ice cream and other dairy products.

Some of the uses to which alginic acid, alginates and their derivatives are put are briefly mentioned in the following two paragraphs.

As a laundry starch substitute alginates have the advantage of being more elastic and tough, and in sizing fill the material better. They may be used in waterproofing fabrics and as mordants for fixing dyes. Synthetic fibres are manufactured from them; combined with wool, a light but warm garment results. The alginates and algin derivatives are used in manufacturing oil drilling muds, cartridge primers, as a binder in printer's ink, in certain liquid soaps and shampoos, in typewriter rollers, in molding material for artificial limbs, in manufacturing buttons, artificial horn, shoe polishes, in photography for film coatings because of its fireproof character (in contrast to a celluloid), in boiler flocculant material, in wall boards, in varnishes, water-base paints, dyes, glues, adhesives, floor coverings, car polishes, rubber substitutes, dental impression materials, ceramic glazes, welding rods, detergents, cleaning compounds, leather finishes, lubricants and insecticides.

Alginates are also used in many pharmaceutical preparations, for example, in emulsions, medicines, tablets, ointments, anticoagulants, lubricating jellies, deodorants, toothpastes, shaving cream, mouth washes, lotions, greaseless hair dressings, lipsticks, cosmetics, cream and skin preparations. They make a batting like cotton but finer and tougher, which will dissolve when used as surgical swabs. Also a surgical thread is manufactured from alginate that dissolves after a certain time has elapsed, so that stitches need not be removed. A whole-blood substitute derived from seaweed has been used in emergency transfusions. It has been found preferable to salt water or sugared water customarily used as an emergency measure in the treatment of shock because it does not break down in the blood stream.

In the food industries, alginates serve as stabilizers for many products such as ice cream, sherbets, chocolate milk, cheeses, desserts, puddings, icings, marshmallow toppings, syrups, candies, salad dressings, flavouring substances, meat sauces, whipping cream, processed meat and in the brewing industry as a clarifier.

OTHER USES OF ALGAE

Industrial Chemicals

Bromine is fairly widespread in occurrence in the marine algae, but it is particularly abundant in *Rhodomela larix* and species of *Odonthalia*, *Polysiphonia* and *Pterosiphonia*. From 3 to 6% dry weight has been found in these species. In times past iodine (or iodides), bromine (or bromides), soda and potash salts have all been prepared in commercial quantities by ashing, particularly when other sources of supply were not available (p. 19). The most recent heavy exploitation of seaweeds as a source of industrial chemicals occurred in the United States in 1914–18, when the supply of potassium and other salts from the Stassfurt deposits in Germany was cut off. This use was partly for the purpose of making acetic acid and acetone by a fermentation process. After extraction of calcium acetate, the residue was worked for potash and iodine as by-products. Acetone and other organic solvents were needed for the manufacture of explosives, and during the emergency the *Macrocystis* beds of California made an appreciable contribution to the supply.

Fertilizers

When the supply of potash from Stassfurt was cut off, interest in seaweeds as a source of fertilizer led to detailed surveys and analyses in the United States. There had been local use of raw seaweeds for fertilizers for many years in New England, Japan, China, Great Britain, France, Canada, Norway and other seacoast countries. Many of the species which were formerly ashed became used regionally as fertilizer, particularly in the British Isles and Norway. *Laminaria*, *Sargassum*, and other seaweeds have been used as fertilizer in Japan. The chief beneficial results of seaweed fertilizers were at first believed to be from the soluble potassium compounds. The total amount of fertilizing constituents in fresh seaweed is comparable to the amount present in barnyard manure, although seaweed contains more potassium salts, less phosphorous and about the same proportion of nitrogen. For this reason it is particularly good for root crops, such as beets and potatoes. Most of the potassium salts are water soluble and immediately available for plant use, whereas the nitrogen and phosphoric acid are released slowly and are available only on decay of the plant body. Thus it is a more effective fertilizer when composted with barnyard manure, which hastens breakdown. Some species however, such as *Ulva*, break down very rapidly. Seaweed fertilizer also has the advantage that it contains no weed seeds and other soil microorganisms such as fungus spores. The potassium content is generally from 3 to 17% of dry matter, nitrogen 1 to 7%, phosphorus (P_2O_5) less than 1%.

Most of the seaweed from which fertilizer was manufactured was harvested in Southern California, but some was obtained in Alaska and in the Queen Charlotte Islands. In 1915 a company formed at Sidney, on Vancouver Island, was using about 30 to 40 tons of raw kelp daily as fertilizer.

A considerable part of the value of seaweed as fertilizer may lie in the provision of trace nutrients and even organic growth substances. Whereas it was formerly believed that plants needed only a small number of chemical elements, it is now known they require many more, although often in extremely minute quantities. Cultivated soil is particularly likely to become impoverished of certain of these substances, which are gradually used up by crops and are only partially replaced by some types of artificial fertilizers. Because of the great number of elements present in sea water which are also found in the algae, it has been found that deficiency diseases in plants can often be remedied by the use of seaweed fertilizer. For example, boron occurs in brown seaweeds in quantities of about 20 to 30 grams per ton, as compared to 3 to 5 grams per ton of animal manure. Seaweed contains 1 to 10 grams of manganese and 2 to 5 grams of copper per ton.

Stiffening Agents

Algal slimes or glues obtainable from a number of marine red algae form the basis of the *funori* industry in Japan. Funori is a material used chiefly for stiffening fabrics. It is a water-soluble sizing which may be used in place of starch in laundering and in the preparation of certain water-base paints. It is also used as an adhesive in hair dressings. It has an advantage in retaining a certain degree of flexibility. Japan produces over $1,000,000 of this product annually. The seaweed is collected by long-handled rakes or by divers. It is dried, partially fermented and bleached to produce a viscous, non-gelling, colloid which is soluble in fresh water. The chief source is *Gloiopeltis furcata*, but species of *Gigartina*, *Iridaea*, *Rhodoglossum*, *Gymnogongrus*, and a few other native species are used in Japan. Species of *Gracilaria* (*G. tenax* and *G. spinosa*) have also been used as a source of cement or stiffeners for fabrics in China.

Carbohydrate Products

In addition to the organic solvents that have been produced by destructive distillation of kelp, another series of chemical products is obtainable—an alcohol motor fuel is one product claimed from *Laminaria digitata*. Various carbohydrate sugars, including mannitol, can be prepared from seaweed products by chemical processes. *Laminaria saccharina* contains 12 to 15% of this sugar. Although these sugars have specialized uses they are not in great demand, but have commercial possibilities. Certain species of *Iridaea* provide a polysaccharide called iridophycin. As yet iridophycin is not used commercially to any extent, but is a potentially useful material having properties rather similar to carrageenin. Although there is little market for it as such, laminarin, which is obtained from a number of kelps, is of potential value since it yields glucose on hydrolysis.

Stuffing and Insulating Materials

Some kelps have been used to stuff upholstery and mattresses. *Ahnfeltia* has been used in the Kamchatka area as a packing material in log cabins. Some algae have been used in the manufacture of fine grades of paper. Some seaweeds have been mixed with asbestos to form a moldable covering for pipes. Some have been ground up and mixed with concrete to produce porosity and insulation. Insoles for shoes have been manufactured from seaweed, and insulation for refrigerator cars and roofs.

Fishing Lines

Nereocystis has been used by the Haida Indians for making lines to catch black cod (*Anoplopoma*) off the Queen Charlotte Islands. The stipes were first soaked and bleached in fresh water, then treated with smoke to keep them flexible and tough, and finally stretched and knotted together to form a fishing line. In parts of Scotland where the brown alga *Chorda filum* reaches a length of 30 to 40 feet a similar use was made of this species. These fishing lines were known by Highlanders as Lucky Minny's Lines.

Occasional and Novelty Uses

A number of novelty items and curios have been made from seaweeds. Knife handles resembling horn, ebonite or vulcanized rubber have been made from marine algae. The Japanese use several species of marine algae that are green when dry for decoration in their homes at New Year's, much as holly is used in North America. In England, species of *Fucus* have been hung up in cottages as crude barometers— the change in appearance of the plants as a result of their hygroscopic qualities indicates a change in the weather. In the preparation of the alcoholic drink from *Nereocystis* already referred to, the long hollow stipe of this alga was used as a worm condenser in distilling the beverage. The Indians employed the plant for bait to catch sea urchins; they used the large floats to store eulachon and dogfish oil and other commodities; the float and hollow portion of the stipe were used to siphon water from their boats.

CONCLUSION

And so the lowly algae—this most ancient group of plants—come into their own. No longer can they be said to be worthless. In this marine flora we have a crop which takes care of itself—we don't have to plant, hoe, spray, prune or fertilize it, least of all water it. This does not mean, however, that we cannot culture and cultivate it and increase our crop, or that it will continue in its abundance regardless of how or when we deplete it. Each species must be considered individually—its natural cycle and reproduction must be known and be accompanied by an intelligent program of utilization and conservation.

REFERENCES

ANON. 1917. Kelp industry in British Columbia. *J. Soc. Chem. Ind.*, **36**: 710.

1947. A report on the location of marine plants of economic importance in British Columbia coastal waters. *British Columbia Res. Council, Tech. Bull.*, No. 4, 5 pp., 8 figs.

1948. Marine plants of economic importance in British Columbia coastal waters. *Ibid.*, No. 10, 9 pp., 7 tables, 9 figs.

1952. *Inst. of Seaweed Research, Musselburgh, Scotland, Ann. Rept.* for 1951. Central Press Ltd. Aberdeen.

1953. *Ibid.* for 1952.

1960. Whole blood substitute derived from seaweed. *Canadian Fisherman*, **47** (2): 34.

ARMSTRONG, E. F., AND L. M. MIALL. 1945. Raw materials from the sea. Construction Publ. Co., England. xi + 164 pp., 21 pls., 21 tables.

BAALSRUD, K. 1955. Utilization of plankton. *Norwegian Whaling Gaz.* for 1955, No. 3, pp. 125–133, 2 tables.

BEHARRELL, J. 1942. Seaweed as a food for livestock. *Nature*, **149**: 306-307.

BERKELEY C. 1925. Note on the organic constitution of Pacific coast kelps. *Contr. Canadian Biol.*, **2**: 505–506.

BIGGAR, E. B. 1917. The potash industry of Canada. *Trans. Amer. Inst. Chem. Eng.*, **10**: 85–103.

CAMERON, A. T. 1915. The iodine content of the marine flora and fauna in the neighbourhood of Nanaimo, Vancouver Island, B.C. *Contr. Canadian Biol.* for 1911–14, Fasc. I, pp. 51–68, tables.

1916a. The commercial value of the kelp-beds of the Canadian Pacific coast. A. Preliminary report and survey of the beds. *Ibid.*, for 1914–15, pp. 25–39, 3 charts.

1916b. The water and iodine contents of some Pacific coast kelps. *Ibid.* for 1914–15, pp. 169–173, 3 tables.

CAMERON, F. K. 1912. A preliminary report on the fertilizer resources of the United States. *U.S. Senate, Doc.* No. 190, 62nd Congr., 2nd Sess.; 290 pp., 18 maps, 39 tables, 19 pls., 3 figs.

1915. Potash from kelp. *U.S. Dept. Agric., Rept.* No. 100, 122 pp., 40 pls., 2 figs., 34 tables.

CARSON, R. L. 1951. The sea around us. Oxford Univ. Press. vii + 230 pp., 5 figs.

CHAPMAN, V. J. 1944. Methods of surveying *Laminaria* beds. *J. Marine Biol. Assn. U.K.*, **26**: 37–60, 15 figs., 4 pls.

1950. Seaweeds and their uses. xiv + 287 pp., 20 pls., 52 figs. Methuen. London.

CHASE, F. M. 1942. Useful algae. *Ann. Rept. Smithsonian Inst.* for 1941, pp. 401–452, 9 pls., 5 tables.

CLARKE, H. T., AND A. MAZUR. 1941. The lipids of diatoms. *J. Biol. Chem.*, **141**: 283–289, 4 tables.

CRIBB, A. B. 1954. *Macrocystis pyrifera* (L.) Ag. in Tasmanian waters. *Australian J. Mar. Freshwater Res.*, **5**(1): 1–34, 4 pls., 23 tables, 16 figs.

DARWIN, C. 1860. Journal of researches. 3rd Ed. New York. 587 pp., 9 figs.

DAWSON, E. Y. 1956. How to know the seaweeds. W. C. Brown. vi + 197 pp., 259 figs., frontispiece.

DELF, E. M. 1943. Nature and uses of seaweed. *Nature*, **152**: 149–153.

DEXTER, R. W. 1950. Restoration of the *Zostera* faciation at Cape Ann, Massachusetts. *Ecology*, **31**(2): 286–288, 1 fig.

DURAIRATNAM, M., AND J. C. MEDCOF. 1954. Ceylon's red seaweed resources. *Ceylon Trade J.*, **19**(4): 1–6, 2 figs.

GILLESPIE, D. C., H. M. BISSETT, J. W. BOYD AND H. L. A. TARR. 1954. A method of facilitating distribution of germicidal substances throughout ice blocks. *Fish. Res. Bd. Canada, Pac. Prog. Rept.*, No. 99, pp. 18–19, 2 tables.

GUBERLET, M. L. 1956. Seaweeds at ebb tide. Univ. Washington Press, xvi + 182 pp., 86 pls.

HARVEY, W. H. 1851. Nereis boreali-americana. Part 1. Melanospermeae. *Smithsonian Contr. Knowledge*, No. 3, Art. 4, 150 pp., 12 pls.

HEYERDAHL, T. 1950. Kon-Tiki, across the Pacific by raft. Rand McNally and Co., Chicago. 304 pp., 42 pls.

HOAGLUND, D. R., AND L. L. LIEB. 1915. The complex carbohydrates and forms of sulphur in marine algae of the Pacific coast. *J. Biol. Chem.*, **23**(1): 287–297.

HUMM, H. J. 1942. Seaweeds at Beaufort, North Carolina, as a source of agar. *Science*, **96**: 230–231.

1944. Agar resources of the South Atlantic and East Gulf coasts. *Science*, **100**: 209–212, 2 tables.

HUMM, H. J., *et al.* 1946. Utilization of seaweeds from the South Atlantic and Gulf Coasts for agar and its decomposition by bacteria. *Duke Univ. Mar. Sta. Bull.*, No. 3, vi + 80 pp., 16 tables, 17 figs.

HUNTSMAN, A. G. 1932. Disease in eel grass. *Biol. Bd. Canada, Atlantic Prog. Rept.*, No. 5, pp. 11–14.

HUTCHINSON, A. H. 1953. Marine plants of economic importance of the Canadian Pacific coastal waters. *Proc. 7th Pacific Sci. Congr.*, **5**: 62–66.

ISAAC, W. E. 1942. Seaweeds of possible economic importance in the Union of South Africa. *J. Bot. Soc. South Africa*, **8**: 225–236.

KAYSER, M. 1919. Utilization of seaweed. *Ind. Eng. Chem.*, **11**: 368.

KIZEVETTER, I. V. 1937a. [Agar-agar from the red alga *Ahnfeltia plicata*.] *Izvestiia Tikhookeanskovo N.-I. Inst. Morskovo Rybnovo Khoziaistia i Okeanografii*, **13**: 1–13. Vladivostok.

1937b. [Comparative physico-chemical characteristics of agar-agars of different origin.] *Biull. Dalnevostochnoi Filiali, Akad. Nauk SSSR.*, **23**: 53–69.

1938. [The seaweeds of the Far Eastern region, their chemical composition and uses.] *Ibid.*, **31**(2): 49–109.

1941. [The maritime weed *Ahnfeltia plicata* as a raw material for the agar-agar industry.] *Zhurnal Prikladnoi Khimii*, **14**: 250–255.

MACFARLANE, C. 1932. Observations on the annual growth of *Ascophyllum nodosum*. *Proc. Nova Scotian Inst. Sci.*, **18**(2): 27–31, 2 pls.

1952. A survey of certain seaweeds of commercial importance in southwest Nova Scotia. *Canadian J. Bot.*, **30**: 78–97, 5 tables, 1 fig.

MACFARLANE, C., AND H. P. BELL. 1933. Observations of the seasonal changes in the marine algae in the vicinity of Halifax, with particular reference to winter conditions. *Proc. Nova Scotian Inst. Sci.*, **18**(3): 134–176, 2 figs.

MACINTYRE, T. M., AND M. H. JENKINS. 1952. Kelp meal in the ration of growing chickens and laying hens. *Sci. Agric.*, **32**: 559–567, 6 tables.

MCKERCHER, B. H. 1945. Agar-like gums and algin from British Columbia seaweeds. *Fish Res. Bd. Canada, Pac. Prog. Rept.*, No. 64, pp. 53–56.

MARSHALL, S. M., L. NEWTON AND A. P. ORR. 1949. A study of certain British seaweeds and their utilisation in the preparation of agar. viii + 184 pp., 12 pls., 14 maps, 23 tables, 5 tables (in appendix), 47 figs. H.M. Stationery Office, London.

MAUTNER, H. G. 1954. The chemistry of brown algae. *Economic Bot.*, **8**(2): 174–192.

MILLER, M. W., AND G. E. PEARSE. 1936. The vitamin D content and hemoglobin building properties of dehydrated kelp for chicks. *Poultry Sci.*, **15**: 19–22, 1 table, 1 fig.

MOORE, L. B. 1941. The economic importance of seaweeds. *New Zealand Dept. Sci., Ind. Res., Bull.* No. 85, 40 pp.

1944. New Zealand seaweed for agar manufacture. *New Zealand J. Sci. Tech., B.*, **25**: 183–209, 8 tables, 16 figs.

1951. Seaweed products in Britain in 1950. *New Zealand Sci. Rev.*, **9**: 180–184, 3 figs.

MORRIS, H. P. 1932. Studies on the nutritive value of kelp meal for animal feeding. *U.S. Dept. Commerce, Tech. Rept.* No. 5.

NEEDLER, A. W. H. 1947. Irish moss industry of the maritime provinces. *Fish. Res. Bd. Canada, Atlantic Biol. Sta., Circ.* No. 10, General Ser. No. 3.

NEWTON, L. 1958. Algin, gift of seaweed. *Bull. Internat. Oceanogr. Found.*, **4**(3): 153–158, 6 figs.

OKAMURA, K. 1925. On the culture of *Gracilaria confervoides*. *J. Imp. Fish. Inst.*, **21**(1): 10. Tokyo.

PRINTZ, H. 1950. Seasonal growth and production of dry matter in *Ascophyllum nodosum* (L.) LeJolis. *Det. Norske Videnskaps-Akad. i Oslo, Mat.-Naturv. Klasse*, 1950, No. 4, 15 pp., 3 figs.

REEDMAN, E. J. AND L. BUCKBY. 1943. Investigations on the use of Irish moss in canning of meat. *Canadian J. Res.*, D., **21**: 348–357, 6 tables.

RIGG, G. B. 1912. Notes on the ecology and economic importance of *Nereocystis luetkeana*. *Plant World*, **15**: 83–92, 8 figs., 1 table.

1942. Extracts from sea plants. *California Fish and Game*, **28**: 207–209.

ROBBINS, W. J. 1939. Growth substance in agar. *Amer. J. Bot.*, **26**: 772–778, 6 figs., 3 tables.

ROBERTSON, G. R. 1930. The agar industry in California. *Indust. Eng. Chem.*, **22**: 1074–1077, 2 figs.

ROSE, R. C. 1953. The requirements for a successful seaweed industry. *Proc. 7th Pac. Sci. Congr.*, **5**: 66–70.

SAIKI, T. 1906. The digestibility and utilization of some polysaccharide carbohydrates derived from lichens and marine algae. *J. Biol. Chem.*, **2**: 251–265.

SANFORD, F. B. 1958. Seaweeds and their uses. *U.S. Fish and Wildlife Serv., Bur. Comm. Fish., Fishery Leaflet* No. 469, 23 pp.

SAUVAGEAU, C. 1920a. Sur des algues marines floridées indigènes pouvant fournir de la gélose. *C. R. Acad. Sci. Paris*, **171**: 566–569.

1920b. Utilisation des algues marines. Encyclopédie Scientifique, Dion. Paris. 394 pp.

1921. Sur la gélose de quelques algues Floridées. *Bull. Sta. Biol. d'Arcachon*, **18**: 5–113.

SCAGEL, R. F. 1948. An investigation on marine plants near Hardy Bay, B.C. *British Columbia Dept. Fish.* No. 1, 70 pp., 11 tables, 26 figs.

1956. Introduction of a Japanese alga, *Sargassim muticum*, into the northeast Pacific. *Fish. Res. Papers, Washington Dept. Fish.*, **1**(4): 1–10, 14 figs.

1957. An annotated list of the marine algae of British Columbia and northern Washington. *Nat. Mus. Canada, Bull.* No. 150, *Biol. Ser.*, No. 52, vi + 289 pp., 1 fig.

1960. The role of plants in relation to animals in the marine environment. *Oregon State College, 20th Annual Biol. Colloquium, Marine Biol.*, pp. 9–29, 5 tables, 2 figs.

SCHWIMMER, M. AND D. SCHWIMMER. 1955. The role of algae and plankton in medicine. Grune and Stratton, New York. x + 85 pp., 9 tables.

SCHOFIELD, W. L. 1935. The harvesting of kelp in California. *California Fish and Game*, **21**: 61–64.

SETCHELL, W. A. 1905. Limu. *Univ. California Publ. Bot.*, **2**(3): 91–113.

SHARP, S. S. 1939. Agar-agar, a new activator for nicotine sprays. *J. Econ. Entomol.*, **32**: 394–395, 1 table.

SMITH, G. M. 1944. Marine algae of the Monterey Peninsula. Stanford Univ. Press ix + 622 pp., 98 pls.

1951. Manual of phycology. Chronica Botanica, xi + 375 pp., 48 figs., tables.

SMITH, H. M. 1905a. The utilization of seaweeds in the United States. *Bull. U.S. Bur. Fish.*, **24**: 169–181, 7 figs.

1905b. The seaweed industries of Japan. *Ibid.*, **24**: 135–165, 25 figs., 4 pls.

SOUTHCOTT, B. A., AND H. L.A. TARR. 1953. Vitamin B_{12} in marine invertebrates and seaweeds. *Fish. Res. Bd. Canada, Pac. Prog. Rept.*, No. 95, pp. 45–47, 1 fig.

STANFORD, E. C. 1884a. On the economic applications of seaweed. *J. Soc. Arts*, **32**: 717–732.

1884b. On algin. *J. Soc. Chem. Ind.*, **3**: 297–301.

1886. Alginic acid and its compounds. *Ibid.*, **5**: 218–221.

SVERDRUP, H. U., M.W. JOHNSON AND R. H. FLEMING. 1942. The oceans. Prentice-Hall Inc., New York. x + 1087 pp., 7 charts, 121 tables, 265 figs., appendix (7 tables.).

SWAN, J. G. 1894. On the economic value of the giant kelp and other seaweeds of the northwest coast of North America. *Bull. U.S. Fish. Comm.* for 1893, pp. 371–376.

TARR, H. L. A., B. A. SOUTHCOTT AND H. M. BISSETT. 1951. Control of rancidity in stored fish. IV. *Fish Res. Bd. Canada, Pacific Prog. Rept.*, No. 88, pp. 67–68.

THORPE, E. 1919. Alcohol from seaweed. *Ind. Eng. Chem.*, **11**: 58.

TIFFANY, L. H. 1937. Algae, the grass of many waters. Charles C. Thomas, Springfield. xiii + 171 pp., 12 figs., 41 pls., 5 table.

TILDEN, J. E. 1937. The algae and their life relations. Univ. Minn. Press, xii + 550 pp., 257 figs.

TOKIDA, J. 1954. The marine algae of southern Saghalien. *Mem. Fac. Fish. Hokkaido Univ.*, **2**(1): 1–264, 15 pls., 4 figs., 5 tables.

TREMBLAY, J. L., AND R. GAUDRY. 1936. Décimation des Zostères (Herbe à Bernaches), dans la région de l'Ile-Verte. *Naturaliste Canadien*, **63**: 257–262.

TRESSLER, D. K., AND J. M. LEMON. 1951. Marine products of commerce. 2nd Ed., Reinhold Publ. Co., New York. xiii + 782 pp., 36 figs.

TSENG, C. K. 1946a. Seaweed products and their uses in America. *J. New York Bot. Garden*, **47**: 1–10, 32–39, 8 figs.

1946b. Phycocolloids: useful seaweed polysaccharides. *In:* Alexander, J., Colloid Chemistry. Vol. 6. Reinhold Publ. Co., New York. pp. 629–734.

TURRENTINE, J. W. 1912. The composition of the Pacific kelps. *J. Ind. Eng. Chem.*, **4**: 431–435, 3 tables.

WALES, J.H. 1944. Fresh ocean fish as a trout diet. *California Fish and Game,* **30**: 43–48.

WOHNUS, J. F. 1942. Products from California kelp. *California Fish and Game,* **28**: 199–205.

WOOD, E. J. F. 1945. The sources of agar in Australia. *J. Australia Coun. Sci. Indust. Res.,* **18**: 263–272, 1 table, pl. 9.

1946. Agar in Australia. *Australian Coun. Sci. Indus. Res., Bull.* No. 203 (*Div. Fish., Rept.* No. 12), 44 pp., 3 figs., 4 pls., 10 tables.

WORT, D. J. 1955. The seasonal variation in chemical composition of *Macrocystis integrifolia* and *Nereocystis luetkeana* in British Columbia coastal waters. *Canadian J. Bot.,* **33**: 323–340, 7 figs., 2 tables.

WUITNER, E. 1933. Les algues marines des côtes de France. cxx + 129 pp., 134 figs., 112 pls.

YENDO, K. 1902. Uses of marine algae in Japan. *Postelsia,* 1902: 3–18, 3 pls.

1914. On the cultivation of seaweeds, with special accounts of their ecology. *Econ. Proc. Roy. Dublin Soc.,* **2**(7): 102–122, 2 figs., pl. 12.

YOUNG, E. L. 1938. *Labyrinthula* on Pacific coast eel-grass. *Canadian J. Res., C.,* **16**: 115–117.