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The distribution of marine algae

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General Distribution of the Algae.

The Algae are typically aquatic plants: about two thirds of the total number of known species are marine,the rest are mostly freshwater. Some forms,however, are well adapted to aerial life,and thrive in any damp situation. On the whole,the larger and more complex algae inhabit the seas, while the smaller and simpler forms grow in freshwater and terrestrial habitats. They represent the oldest type of vegetation.

The simplest and most primitive algae are the Myxophyceae,which are of great interest from the standpoint of ecology on account of their striking capacity for existence under the most varied and adverse environmental conditions. In fact,Myxophyceae of all kinds live in glacial and alpine regions,being able to withstand prolonged and repeated freezing. Chorda has often found in the Swiss mountains Myxophyceae living at -10 C. On the other hand,they constitute,together with bacteria,the principal vegetation of hot springs: about 41 species,amongst which Phormidium laminosum,Aphanothece termalis,and Mastigocladus laminosus are conspicuous,have been found thriving in termal waters at temperatures ranging from 50 to 80 C. Harvey found in Beryl Spring,North America,one species of

Phormidium living at 89 C. The Myxophyceae are essentially tropical plants. They are found mostly in fresh water,being prominent in the plankton of ponds and lakes. A large number of species are terrestrial: in the damp soil and rocks of tropical regions there is always an abundant algal flora composed almost entirely of Myxophyceae. Along the seashore they grow in tide pools,on dripping rocks, and clothing the fronds of larger marine plants. A few genera and species form part of the plankton of tropical seas. Many Myxophyceae are epiphytes,such as the genera Pleurocapsa,Dermocarpa,and Camaesiphon. In brief,the Myxophyceae occur in every conceivable situation where there are enough light and moisture to meet their exiguous needs. According to Tilden,there are about 548 freshwater and aerial species together,105 are marine,and 24 grow in marshes.

The Chlorophyceae attain their greatest development and abundance in fresh water. The marine forms belong mostly to the small orders of the Ulvales,Siphonocladiales,and Siphonales,all of which include also freshwater species. The Conjugales occur only in fresh water,but the other orders are represented in marine habitats by a few species. The Chlorophyceae are very important constituents of the freshwater plankton,but they are conspicuous by their absence from the floating vegetation of the sea. Some Chlorophyceae,for instance Chlamydomonas nivalis,Protococcus viridis,and Ankistrodesmus nivalis,occur in the regions of perpetual snow forming large colonies which,amidst the whiteness of the environment,look like patches of colored snow. Chlamydomonas nivalis contains a large amount of haematochrome- a red modification of chlorophyll,and its cells occur embedded in the snow to a depth of several centimetres,thus giving rise to what is known as red snow. Likewise,Protococcus viridis and Ankistrodesmus nivalis impart to the snow,respectively,yellow and green tints. Some glacial and alpine Chlorophyceae are able to live,in their vegetative condition,even at -10 C. Of course,their resting spores can endure much lower temperatures. Many Chlorophyceae are epiphytic in habit,such as the genera Coleochaete,Aphanochaete,and Trentepohlia;while others are endophytic, such as Endoderma,Acrochaete,and Blastophysa. To conclude,the Chlorophyceae are nearly as widely spread as the Myxophyceae in freshwater and aerial situations,but less abundant in the seas.

Certain Myxophyceae and Chlorophyceae normally occur intimately associated with fungous mycelia,chiefly of Ascomycetes,rarely of Basidiomycetes,forming the compound organisms called Lichens. The conjoint life of such algae and fungi is in the majority of instances mutually beneficial;that is,they are cases of symbiosis. In some instances,however,the fungi are undoubtedly parasitic on the algae;conversely,examples are known wherein the algae are parasitic on the fungi. The dual nature of the lichenous thallus was conclusively demostrated by Bonnier,who synthesized lichens by bringing together cultures of certain algae and fungi. In many instances,particularly regarding the Myxophyceae,the algal symbionts can be readily assimilated to forms known to exist also independently,but the fungous symbionts all have undergone great changes as a result of their symbiotic mode of life.

Amongst the Myxophyceae that commonly form part of lichens are Gloeocapsa,Chroococcus,Nostoc,Stigonema,Scytonema,and Rivularia. The exact species have been identified in only a few instances: Gloeocapsa montana is found in the lichens Baeomyces roseus and Omphalaria umbella;Nostoc punctiforme in Peltigera,Pannaria,and Stictina;Nostoc sphaericum in Hydrothyrea;Rivularia nitida in Polychydium and Lichina;and Stigonema panniforme in Ephebe pubescens.

The Chlorophyceae that enter in the formation of lichens belong mostly to the Protococcaceae,but it is a most difficult task to identify their genera,to say nothing of the species. Apart from members of the Protococcaceae,species of Trentepohlia occur in the thalli of Arthronia,Graphis,Racodium,and Gyalecta.

Some Chlorophyceae occur symbiotically associated with various animals;for instance,a species of Chlorella is found in the endodermal cells of Hydra viridis,and a species of Carteria in the cells of Convoluta Roscoffensis.

The Phaeophyceae and Rhodophyceae,which are the most highly differentiated algae,are essentially marine groups,being represented in fresh water by a few genera of reduced and even vestigial nature. They occur in the intertidal zone of all rocky seacoasts,and extending downwards to a depth of about 150 metres. The principal freshwater Phaeophyceae are Lithoderma,Phaeothamnion,and Pylaiella. The Rhodophyceae include more freshwater forms: the genera Thorea, Lamanea,Stenocladia,Batrachospermum,and Balbiana grow exclusively in fresh water;and Bangia,Chantransia,Caloglossa,Bostrychia,and Delesseria contain each one or more freshwater species.

Of the remaining algal groups,the Charales are strictly confined to fresh water;the Peridineae are chiefly marine;and the Diatomaceae are equally abundant in marine,freshwater,and terrestrial habitats. About 125 species of Peridinians have been described,of which only 15 inhabit fresh water. The number of known species of Diatoms is amazingly large,probably 12,000;approximately half of them are marine,the rest freshwater and terrestrial. Diatoms are amongst the commonest living beings: they are as widely distributed and occur in as varied situations as the Myxophyceae and Chlorophyceae together. A few Diatoms uccur in the cryoplankton- that is,the flora and fauna of the regions of perpetual ice and snow; and few others occur in hot springs at temperatures as high as 55 C.

Ecological Classification of the Marine Algae.

The marine algal flora is,therefore,constituted by the Phaeophyceae,Rhodophyceae,and Peridineae,all of which are essentially marine organisms, by the Diatomaceae,and a comparatively small number of Myxophyceae and Chlorophyceae.

Marine algae belong to one or the other of two main ecological groups,the plankton and benthon. The term plankton was introduced by Haeckel to designate all the living organisms,generally of microscopic size,which drift about passively in the surface of oceanic as well as in continental waters: they may posses organs of locomotion such as cilia,but their movements are chiefly determined by winds,currents,and tidal streams. In contrast with planktonic organisms are those,also aquatic,that grow attached to the substratum,and which are given the collective name,coined by Warming,of benthon. For the sake of exactness,when referring exclusively to plant life the words phytoplankton and phytobenthon are used instead of simply plankton and benthon respectively.

In the sea,as over the land,animals are wholly dependent upon plants for food. There are two main types of nutrition in nature: holophytic,exemplified by ordinary green plants;and holozoic,exemplified by animals. Plants,by means of the chlorophyll and under the action of sunlight,synthesize from inorganic compounds- water, carbon dioxide and certain mineral salts-all the organic substances they require for the building and maintenance of their own bodies. Animals,on the contrary,consume only complex chemical substances forming part of,or produced by,other animals or plants. In other words,animals must find in the environment already elaborated food materials;that is,carbohydrates,fats,and proteins.

The phytoplankton is the largest ecological group in the sea; and,as regards the production of organic matter,it is also the most important. It consists of Diatoms,Peridinians,and Myxophyceae, all of which occur in prodigious numbers spread throughout the surface of the oceans: according Johnstone there are, on the average, from 100 to 500 millions of planktonic algae beneath every square metre of sea. The phytobenthon consists chiefly of Phaeophyceae and Rhodophyceae; and, in contrast with the phytoplankton, it is confined to a narrow coastal belt. The phytoplankton is almost entirely the ultimate and sole source of food for marine animals: the benthonic algae are hardly used by them as food materials.

The Phytoplankton.

We may now make a general survey of the various types of planktonic algae.

The Diatoms are the most abundant marine organisms. It has been calculated that in the North Sea there are during spring no less than 5400 millions of Diatoms beneath every square metre of surface. Brandt made a haul in the Baltic Sea through two cubic metres of water gathering about 3170 millions of Diatoms; nay, he estimated that one third of the above number of Diatoms had escaped through the meshes of the net. Diatoms are most abundant in cold latitudes, showing a marked preference for cold water. In Arctic and Antarctic seas they form myriads of colonies, each composed of countless individuals.

Although the dry substance of Diatoms contains but 10 per cent of protein, 22 per cent of carbohydrate, 2.8 per cent of fat, and 65.2 per cent of ash, the smaller marine animals such as Protozoa and Crustacea, and consequently marine animal life as a whole, are mainly dependent upon them as an ultimate source of food. A happy metaphor describes Diatoms as "the pasture of the seas". That Diatoms are the most important producers of organic matter in the sea,is evident from the following facts: from March to May the plankton of temperate and polar seas is composed almost entirely of Diatoms: out of each million of planktonic organisms collected at random 999,999 are Diatoms. Moore,by means of the fall of H-ion concentration which takes place in the sea water when carbon dioxide is withdrawn from it,was able to measure fairly accurately the rate of photosynthesis in the phytoplankton: he estimated that the quantity of carbon dioxide consumed by the phytoplankton during spring is at least 8.8 milligrams per litre,which corresponds to a total production of 300,000 kilograms of carbohydrate per square kilometre of sea. Compared with moist organic matter such as land crops,the production in the oceans amounts to at least 10 tons of moist vegetation per acre of surface.

Amongst the commonest genera of Diatoms are Chaetoceras,Rhizosolenia,Coscinodiscus,Biddulphia,Thalassiothrix,Coscinosira,Bellerochea,and Dytilum. The genus Chaetoceras contains numerous species,most of which occur abundantly in the North Atlantic: as many as 150 millions have often been gathered by a small tow-net in a single haul. Rhizosolenia is another large genus,also exceedingly common: no less than 180 millions have been sometimes obtained in one haul of the tow-net in June. The majority of marine Diatoms belong to the order of the Centricae.

Next to Diatoms,the Peridinians are the most important constituents of the marine phytoplankton,being particularly abundant in warmer seas. In certain regions they are so abundant as to impart a distinct coloration to the water: Ceratium volans is the cause of the brownish purple color that the Indian Ocean exhibits at times,Gonyaulax polygramma turns brown the water of the Japanese seas in summer,and Gonyaulax polyedra gives red tints to large areas of sea off the coast of California. Some Peridinians,for instance Ceratium tripos and Pyrocystis pseudonoctiluca,exhibit luminescence. The various species of the genus Pyrocystis,which abound in tropical and subtropical seas,are the principal cause of the diffuse luminosity seen in such seas during calm weather. Amongst the commonest Peridinians are those belonging to the genera Ceratium,Peridinium,Gonyaulax,Gymnodium,and Pyrocystis. In contrast with Diatoms which often form large colonies of varied and characteristic patterns,the Peridinians usually occur singly. The Peridinians are the dominant organisms in the plankton of open seas and of tropical waters.

The Myxophyceae which occur in the marine plankton belong mostly to the Oscillatoriaceae,and inhabit chiefly tropical waters. The most important genera are Trichodesmium and Heliotrichum. The Red Sea owes its characteristic hue of red to the presence in vast quantities of Trichodesmium erythraeum,which occurs as clusters of short filaments irregularly distributed over the surface of the water: it may occupy narrow tracts several miles in length,or patches of large area,and then be totally absent in the adjoining spaces. Certain Myxophyceae,nevertheless,are conspicuously abundant in temperate seas,such is the case with some species of Nodularia: the greenish grey appearance of the Baltic Sea is produced by Nodularia spumigena. According Hensen,there are in the Bay of Kiel during summer about 3 millions of Nodularia spumigena per litre.

The power of floatation shown by planktonic organisms is undoubtedly their most characteristic feature. As planktonic algae have generally a greater specific gravity than sea water,they tend to increase their body surface in order to reduce their relative weight. Thus,we find that many floating Diatoms are extraordinarily large: a typical instance is that of Coscinodiscus rex,which resembles a cylindrical box and measures over a millimetre in diameter. Other planktonic Diatoms are provided with especial arrangements for floatation such as wing-like expansions,long spines,horn-like outgrowths,and bristles,all of which increase greatly the friction of the body against water and,therefore,make sinking more difficult. The body itself may be ribbon-like,filiform,boat-shaped,et cetera. To mention a few instances at random: Corethron Valdiviae has numerous and long bristles,Planktoniella sol is discoid in shape and possesses a hollow floating wing,and Rhizosolenia hebetata-semispina is fusiform. Still other Diatoms,such as the various species of Thalassiosira,secrete long filaments of mucilage which act as an effective suspension apparatus. In general,planktonic Diatoms posses thin walls and contain a large central vacuole filled with a liquid of about the same specific gravity that sea water. The Peridinians, in addition to organs for floatation similar to those exhibited by Diatoms,are generally provided with a pair of flagella by which they can move actively. The following Peridinians are of interest on account of their suspension organs: Ceratocorys horrida,which is beset by numerous long spines;Ornithocercus splendidus,provided with an encircling wing that forms a parachute;and Ceratium trichocerus, as its name implies,is endowed with three very long horn-like processes. The planktonic Myxophyceae posses generally air vacuoles, which of course reduce their specific gravity. Most Myxophyceae, moreover,are surrounded by mucilage which,without being an adaptation to the planktonic mode of life,helps them to keep afloat. Finally,large number of floating organisms store food in the form of fatty oils,substances lighter than water.

Spatial Distribution of the Phytoplankton.

On the whole,the phytoplankton is much more dense in frigid than in tropical waters. The Plankton Expedition in 1889 showed that much larger hauls of planktonic algae can be obtained in polar and temperate seas than in tropical ones;and Lohmann proved that the Baltic phytoplankton is markedly richer than that of the Mediterranean Sea. Two facts,according Brandt,account for the relative poverty of the tropical phytoplankton: first,the amount of oxygen and carbon dioxide- of gases in general-which water can contain in solution decreases as the temperature increases;and second,the inorganic nitrogen compounds,essential to plant life,are broken down into elementary nitrogen,which most plants cannot utilize directly,at a more rapid rate in tropical waters than in those of polar and temperate regions. The oxygen,carbon,and nitrogen supplies are,therefore,deficient in warm waters,hence the relative sparsity of the marine tropical flora,and consequently of the fauna. (The process known as denitrification is brought about in nature by the denitrifying bacteria,which are exceedingly numerous in tropical seas,but rare or absent in frigid ones). The largest hauls of planktonic organisms have hitherto been obtained in Arctic and Antarctic seas. Nevertheless,the alleged poverty of the tropical and subtropical plankton cannot be regarded as a constant condition,for Kofoid has recorded very large gatherings of Peridinians and Diatoms in the Humboldt current off the west coast of America,and the Challenger Expedition made some of its largest hauls in the equatorial Pacific Ocean. Probably,on the whole,oceanic currents have more to do than latitude or temperature alone with the relative density of the plankton in the different seas.

The distribution of the phytoplankton in depth is mainly dependent on sunlight. The solar rays penetrate into the sea only to a certain distance which,obviously,varies according to latitude: thus, while at the equator the diaphanous zone may extend 1000 metres and even more downwards,in polar regions it measures at the most 40 or 50 metres. (The portion of the ocean illuminated by sunlight is called diaphanous or photic zone,in contrast with the opaque region). On the average,the light and heat of the sun hardly go beyond 600 metres from the surface of the sea. As plants are dependent on light for the synthesis of organic compounds,the phytoplankton is naturally confined to the upper part of the diaphanous zone,where not only light but also oxygen and carbon dioxide are at the optimum.

Schimper,during the Valdivia Expedition,made systematic observations regarding the vertical distribution of floating marine algae. He found that the phytoplankton is practically limited to the uppermost 200 metres,and that the maximum is found in the zone between 20 and 80 metres from the surface. Hjort,who carried out investigations on the same subject all the way from the Canaries to Newfoundland,confirmed the results obtained by Schimper. Hjort examined samples of water from the surface,and from 20,50,75 and 100 metres,invariably finding that the greatest number of planktonic algae occur from 15 or 20 to 75 or 80 metres below the surface, that beyond 75 metres their number rapidly diminishes,and that below 100 metres plant life is very scanty. From observations made in the Pacific Ocean,Kofoid concludes that most Peridinians live within 200 metres from the surface,and that below 100 metres large percentage of individuals show degenerative changes in their plastids,and low vitality.

Another fact worth noticing regarding the distribution of marine floating plants is that a great many species have a very large area of distribution. On land,plants and animals are restricted by often insurmountable geographical barriers,such as deserts,mountains,rivers,and oceans. In the sea,on the contrary,physical conditions are far more uniform than over the continents,and marine currents afford excellent means of distribution. Even temperature,which is the most effective physical barrier that marine organisms encounter,varies much less in the sea than on land: the extremes of temperature in the sea are -3 C. and 31 C.,a range of 34 C.,while the extremes over the land are -90 C. and 65 C.,a range of 155 C. The result is that in the oceans extensive areas have a more or less uniform flora and fauna. Apart from such cases of wide distribution of similar life, there are numerous instances of single species spread throughout very large tracts of ocean. Thus,we find that certain species of Diatoms that inhabit the Chinese seas inhabit also the North Atlantic;and Peridinians that occur off the coast of California occur also off the coast of Norway.

The density of the phytoplankton is greater in coastal waters than in the open sea;in fact,the littoral region may be regarded as the nursery where planktonic organisms begin to develop and whence they spread into the open sea. This is probably due to the fact that,as a result of drainage from the adjoining land,the amount of certain essential mineral salts,particularly nitrates,is greater nearer the coast.

The planktonic algae may be classified into two ecological groups according to their occurrance in coastal waters or out in the open sea. There is a whole series of algae which occur only along the coasts unless they have drifted out in the ocean,where they generally perish;such algae are said to be neritic. In contrast with them are others which normally occur in the open sea,and are called oceanic. Diatoms are mainly neritic organisms,while Peridinians are chiefly oceanic. The marine Myxophyceae inhabit mainly coastal waters,but Trichodesmium and Halosphaera occur out in the ocean. Several reason are given why the neritic algae avoid the open sea;of these,the principal are that they need the more abundant supply of nitrogen compounds found in coastal waters,and that the higher salinity of the open ocean is lethal to them. But we are at loss in explaining why the oceanic species cannot live in the vicinity of the coast. As a matter of fact,the cause or reason underlying the division of planktonic algae into neritic and oceanic species is practically unknown. The salinity differs in coastal and open sea waters,but the investigations of Allen and Nelson on the culture of Diatoms in artificial sea water have shown that the salinity may be varied to an extent even greater than the natural variations in the sea without appreciable effect on marine algae.

Seasonal Distribution of the Phytoplankton.

The density of the phytoplankton varies according the climatic variations of the year. The cause of the numerical changes of the phytoplankton throughout the year is not yet well known;but,it is safe to say that solar radiation is the physical factor that chiefly,not wholly,determines the relative abundance of planktonic algae at the different seasons.

Within certain limits,the rate at which cell division takes place in plants accelerates as the intensity of sunlight increases: with increased sunlight,photosynthesis attains its maximum,and consequently growth is more active.

From November to March there is a general poverty of life in the sea. As spring approaches,the intensity of sunlight increases daily and Diatoms,Peridinians,and Myxophyceae begin to reproduce more or less actively,so that at the end of winter and beginning of spring there is a general outbreak of plant life in the sea.

Diatoms attain their maximum abundance from April to June;afterwards,notwithstanding that the climatic conditions are still propitious to active metabolism,their number begins to decrease,and this decrease lasts for several months. Diatoms are scarce throughout summer and early autumn,but in November they become again abundant. Finally,as winter advances,they rapidly diminish to a minimum once more.

Peridinians and Myxophyceae undergo a seasonal cycle similar to that of Diatoms,but their maximum abundance coincides with the period when the latter are decreasing in number. Moreover,the annual cycle of the Myxophyceae often includes only two phases: a period of scarcity from about December to April,and a period of abundance from June to November.

The phytoplankton,as a whole,attains its maximum density in the sea from April to July. From June onwards the zooplankton- that is,the floating small animals,rapidly increases,preying upon the phytoplankton.

Not all the species of Diatoms or Peridinians become abundant simultaneously,but each species attains its maximum at a particular and more or less definite date. The result is that at a given time of the year certain forms are dominant in the sea,while others are scarce. For instance,the first to become abundant as spring nears are the species of Coscinodiscus and Biddulphia,which attain their maximum from March to early April;then follow the numerous species of Chaetoceras,which are characteristic of late April and early May;and from late May to July the dominant forms belong to the large genus Rhizosolenia. During their period of maximum abundance, any of these kinds of Diatoms may be so abundant as to discolor the sea. Then,again,some species of Chaetoceras,Rhizosolenia,and Biddulphia help to constitute the autumnal Diatom maximum. Amongst the Peridinians the same phenomenum or succession of species throughout the year takes place;two instances may serve as way of illustration:

the genus Peridinium is present in the plankton all the year round, but it occurs abundantly only in May and June;afterwards,it slowly decreases to give place to the various species of Ceratium,which attain their maximum from late June to early August. The foregoing remarks apply only to the phytoplankton of frigid waters: practically nothing is known regarding the seasonal changes of the tropical phytoplankton. Of course there are many other species of Diatoms and Peridinians which may serve equally well as examples,but it is needless to name more instances: the already mentioned suffice for our purpose.

The Phytobenthon.

The phytobenthon,as we have already stated, includes the Phaeophyceae,Rhodophyceae,and a small number of Chlorophyceae. We may also consider as members of the phytobenthon certain Diatoms which form fixed colonies.

The Phaeophyceae or brown algae grow between the tidal marks and extending downwards to about 40 metres below low water-mark. The thallus is normally attached to the substratum by means of a holdfast,whose function is purely mechanical,not absorbent. The holdfast varies in form: that of Fucus vesiculosus or Laminaria solidungula is discoid,while that of Laminaria saccharina or Macrocystis pyrifera is branched like a root.

The gulfweed Sargassum is exceptional in being able to lead a pelagic life;but its normal condition is attached to stones or rocks like the rest, and while floating cannot reproduce save by vegetative budding. In the great ocean eddy called the Sargasso Sea several species of Sargassum, originally derived from fixed species of Central America and West Indies, have accumulated in vast quantities, and lead exclusively a pelagic existence. In the Pacific Ocean there occurs another pelagic species of Sargassum, Sargassum natans. Also Macrocystis pyrifera is frequently found floating off the west coast of North America.

The Phaeophyceae occur in all rocky seacoasts, ranging from Arctic and Antarctic regions to the tropics, but they are most abundant and attain their greatest development in frigid waters, where they form extensive and dense immersed forest-associations. The most important Phaeophyceae of temperate and glacial coasts belong to the genera Laminaria, Desmarestia, Macrocystis, Nereocystis, Postelsia, Ascophyllum, and Pelagophycus. Perhaps the most familiar Phaeophyceae are the various species of Fucus, which cover extensive areas in the littoral of temperate regions of the northern hemisphere.

In the Pacific coast of America, from Alaska to California, the Phaeophyceae grow in great quantity and variety. There are found no less than 20 genera of Laminariaceae: Phyllaria, Laminaria, Hedophyllum, Arthrothamnus, Pleurophycus, Cymathaere, Costaria, Agarum, Thalassiophyllum, Lessonia, Dictyoneuron, Postelsia, Nereocystis, Macrocystis, Pelagophycus, Lessoniopsis, Pterygophora, Alaria, Eisenia, and Egregia. Some of these plants,especially Macrocystis pyrifera, Nereocystis luetkeana,Alaria fistulosa,and Pelagophycus porra,are of great commercial importance because of their large content of Potassium. Samples dried in the oven at 105 C. contain from 9 to 30 per cent of potassium salts. Macrocystis pyrifera grows in extensive beds or groves several kilometres in length and from 50 metres to 2 kilometres in width;and its thallus is usually from 25 to 35 metres in length,but sometimes it measures 250 and even more metres. Nereocystis luetkeana and Alaria fistulosa grow together forming also large beds,and their thalli attain large dimensions,but they are always much smaller than Macrocystis pyrifera. Pelagophycus porra contains on the average more potassium than any other brown algae,but it occurs in scattered small groups or single plants not sufficiently abundant to be of commercial importance in itself.

The Antarctic Phaeophyceae are also of gigantic size,witness the massive Lessonia and Desmarestia. The main axis of Lessonia is often 12 to 16 centimetres in diameter. In the North Atlantic the most common forms belong to the genus Laminaria,being from 6 to 10 metres in length. In the tropical seacoasts the dominant forms are Cystoseira and Sargassum,which at best measure from 1 to 2 metres in length. The Dictyotaceae,Cutleriaceae,and Sporochnaceae are essentially tropical families,and include only small plants.

As we have seen,the brown algae become markedly smaller as we approach to the equator. The cause of the greater development of glacial and temperate Phaeophyceae as opposed to tropical forms is probably the same cause responsible for the greater abundance of planktonic organisms in frigid waters,namely,that the carbon,oxygen, and nitrogen supplies are more adequate in cold than in warm water.

The principal conditions for growth and occurrence of brown algae are two: a rocky substratum to furnish anchorages to which the holdfasts may be attached,and a considerable movement of the water to insure continuously renewed supplies of the essential gases and salts.

Observations have been made in various parts of the world regarding the density of the brown algal groves. In the Pacific coast of Noth America the beds of Macrocystis and Nereocystis contain from 9 to 25 plants per square metre. In the coasts of the British Islands Laminaria occurs in beds containing as many as 30 plants in an equal area. In the coasts of New England the Fucus groves are very dense: in one case,at the zone where Fucus begins,35 stalks of Fucus serratus were counted in one square metre,and in another instance 250 stalks of Fucus vesiculosus in an equal area.

Most Phaeophyceae are perennial,showing vegetative activity during the summer and reproductive activity during the winter. Laminaria Cloustonii is known to live 12 years. On the other hand,Nereocystis and Chorda are generally annual,they disappear in the winter and reappear in the spring. The Laminariaceae shed their blades more or less yearly,but the stipes and holdfasts,or at least the holdfasts, are as a rule perennial. Schimper found in Arctic regions Phaeophyceae active during the dark polar winter and at temperatures varying from -3 C. to 0 C.

The Rhodophyceae characterize the lowest algal zone of all seacoasts. They exhibit a wide variety of forms,but are usually small in size. They occur attached to the bottom of the sea by means of rhizoid holdfasts.

The Rhodophyceae become rare at about 50 metres from the low water-mark;Verril,however,has dredged red algae 6 centimetres long attached to bowlders at a depth of 150 metres off Eastport,Maine. In tropical waters they probably grow at even greater depths. In contrast with other algae,they are equally distributed in both frigid and tropical waters.

In the temperate zone the commonest red algae are Porphyra,Polisiphonia,and Chondrus. Among the most important forms are Chondrus crispus,Delesseria sanguinea,Gigartina mamillosa,Sphaerococcus lichenoides,Gilidium corneum,Euchenma spinosum,and Gelidium cartilagineum. From the last four named species,which occur in vast quantities in the coasts of Japan,Java,Ceylon,and Madagascar,agar-agar is chiefly obtained. The Corallinaceae are very plantiful in the tropics, where they take an important part in the building of reefs;in fact, often they far outrank the corals in importance as reef-builder.

The Chlorophyceae are found in the intertidal zone attached to the sand by means of rhizoids;below the low water-mark they are extremely rare. In colder seas the Chlorophyceae are of little importance,except for some Ulvaceae and Cladophoraceae. In the tropics, besides the said forms,there are three characteristic families,the Codiaceae,Valoniaceae,and Caulerpaceae. Among the commonest marine green algae are the genera Ulva,Caulerpa,Cladophora,Acetabularia, Bryopsis,Monostroma,and Enteromorpha. Certain calcareous green algae, of which Halimeda and Lithothamnium are perhaps the principal,are very important reef-builders. The tropical marine Chlorophyceae develop luxuriantly,forming great masses sometimes extended to a depth of 25 or 30 metres. There are also a few small marine genera of Ulotrichales and about six species of Protococcales. Tichet has shown that many of the marine Chlorophyceae exhibit a great power of accomodation to changes in the salinity of the water;for instance,certain species of Cladophora are able to withstand a salinity from 2 per cent to 9 per cent.

The coastal region occupied by the phytobenthon may be divided into three zones: the littoral,or intertidal zone;the sub-littoral, which extends from the low water-mark to about 40 metres downwards; and the elittoral,which is below the preceeding and extends as far down as the diaphanous zone. The Chlorophyceae predominate in the upper part of the littoral;the Phaeophyceae in the lower littoral and upper sub-littoral;and the Rhodophyceae in the lower sub-littoral. In the elittoral there are only Rhodophyceae,but few.

The "Chromatic Adaptation" of Algae.

The algae are classified according to their color into five classes: Myxophyceae,Chlorophyceae, Phaeophyceae,Rhodophyceae,and the heterogeneous group of the Xanthophyceae. This classification,however,is not as artificial as it first seems: the differences in color exhibited by the various algal classes are closely parallel to important differences in structure and reproductive methods. Moreover,as we have seen,each class exhibits characteristic ecological features.

The Chlorophyceae contain the pigments which are normally present in ordinary green plants;namely,chlorophyll a, and chlorophyll b,carotin and xanthophyll. The same is true of the Xanthophyceae, with the difference that they contain relatively larger amounts of carotin and xanthophyll. In addition to these pigments,the Phaeophyceae contain a brown pigment- fucoxanthin,which is the cause of their characteristic color;and the Rhodophyceae a red one- phycoerythrin. The Myxophyceae contain only chlorophyll a, and chlorophyll b,and a blue pigment- phycocyanin. There are good reasons to believe that these accessory pigments have an adaptative significance.

Ordinary green plants utilize in photosynthesis chiefly the red light of the solar spectrum,this being the case with green algae. The chlorophyll develops its maximum activity under red light, which is the light most strongly absorbed by it. Engelmann,by means of an ingenious experiment,demostrated that the energy used in photosynthesis is exclusively derived from the solar rays absorbed by the plastids of plants. The experiment is this,a filament of green alga living and carrying on active photosynthesis in water is illuminated by means of a solar spectrum so that different portions of the filament are illuminated by rays of different color. A culture of Bacterium termo,which is very sensitive to oxygen,so that its cells always move towards any source of oxygen,is then placed near the illuminated algal filament. The bacterial cells soon move and cluster around the portions of the alga illuminated by the rays corresponding to the principal absorption bands of chlorophyll, chiefly in the red. The behavior of the bacteria show under what kind of light oxygen,which is one of the products of photosynthesis,is being set free more actively.

But the presence of other pigments in a plant modifies the absorption spectrum of chlorophyll. Thus,the brown and red algae absorbe chiefly yellow and green rays respectively. In the Phaeophyceae photosynthesis attains its maximum under yellow light,and in the Rhodophyceae under green.

The distribution in depth of the marine algae is as follows: the green and yellow-green algae occur mainly near the surface of the water,brown algae occur usually at greater depths,and red algae inhabit the deepest algal zone. Why the different classes of algae are found generally at different depths?

Spectroscopic investigations show that the penetrating power of the light into water varies for the different kinds of rays of the spectrum. In general,the penetrating power of a ray of light depends on the length of its waves,the shorter its waves are,the deeper it enters into the water. Red light,which consists of the longest light waves,is entirely absent at a short distance from the surface,say 40 metres. Orange and yellow rays penetrate to a depths of 180 metres,and green go even deeper- 325 metres. The blue and violet rays go down 1200 metres and even more in the tropics. The light rays are,then,gradually absorbed by water in the order of the spectrum: first red,then orange,yellow,green,blue,and finally violet.

As we have already stated,in the red algae photosynthesis attains its maximum under red light,and we find that this is the light predominating in the zone where they chiefly grow. Green pigmentation is of course transparent to red light and,therefore,inefficient in that situation.

There is,therefore,a definite relation between the pigmentation of the various algal classes and their habitats. Algal species which occur both deeply and near the surface of the water commonly differ in color in the two habitats: red algae growing near the surface are,as a rule,greener than those growing at lower depths. The red algae Lamanea,Delesseria,Batrachospermum,et cetera,which grow in fresh water exposed to ordinary light,are greenish in color. To sum up,the algae,as a rule,posses a color complementary to that of the light prevailing in their habitat.

Experiments performed with great care have shown that certain algae actually develop a new pigmentation when grown under the action of a colored light,that the color they acquire is complementary to that of the light to which they have been exposed,and that the longer the plants remain under such light the more pronounced or distinct is the new pigmentation.

The alga Oscillatoria sancta occurs in several colors ranging from bluish green to reddish. According to Engelmann,cultures of a greenish variety become reddish when they develop in green light, and brownish in blue light. The reddish varieties become greenish when exposed to red light.

Harder,working with Phormidium foveolarum,has recently confirmed the results obtained by Engelmann. This plant develops a green color in red light,and a dark purple color in blue light. Harder found also that the more intense is the colored light used the more promptly is the response produced. Finally,he discovered that algae carry on photosynthesis best in light of the same color and the same intensity as that prevailing in their habitats.

Gaidukov called this tendency of the algae to develop a color complementary to that of the light in which they grow the law of complementary chromatic adaptation. Although this law is far from holding true in every instance,it gives on the whole a satisfactory explanation of the general distribution in depth of the different algal groups.

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