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LIFE IN THE OCEAN.¹

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On account of the favorable situation of the University of Kiel on the seacoast, a part of the corps of instructors of the university has, for a long time, but especially since the creation in 1870 of the Kiel commission for the scientific study of the German seas, directed its labors principally toward the study of the phenomena of life in the ocean.

The field is vast; it not only brings rich harvests to zoologists, botanists, and oceanographers, but also supplies valuable data to the chemist, the physicist, the physiologist, and hygienist. Our university, which originally had rather the character of a provincial institution of Schleswig-Holstein, has been insensibly metamorphosed into a special German university for the study of the things of the sea, while a part of our instructors at the same time teach in the naval academy. This specialization has been made known abroad by the fact that the first great German expedition for marine exploration, called the Plankton expedition, was carried out by members of our university. To the work of the commission for the scientific study of the German seas is due also the particular character of the researches carried on at Kiel during the second half of the century now closing, that is, since biological study of the ocean has been somewhat extended. The commission was assigned the task especially of investigating marine phenomena from the point of view of the exploitation of their animal resources; its labors mark the first step in a course having for its principal aim the discovery of the general laws which govern the phenomena of marine life, and of which the knowledge is necessary for the best success of the fisheries.

Questions of general biology have thus been brought to the front, and methods have been invented for penetrating the secrets of the deep for the profit of mankind. We are still far from our goal. For to reach it, observations, however numerous, on the behavior of the organisms that live in the sea, or their mutual relations, and on the

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influence of external conditions, will not suffice; it is requisite besides to extend the conquests of science to the things of the sea, and to apply to the special beings that live therein the fundamental principles and approved methods of animal and vegetable physiology which have been deduced from the terrestrial world. We may sum up all these researches as the science of the totality of exchanges of matter in the ocean, and I will indicate here the most important of the investigations and the facts which must form the basis for the solution of the problem. I shall dwell especially on those points which present a general interest.

Matter in nature follows a cycle which may be briefly described as follows: The constituents of the air, the water, and the earth are transformed by vegetation into living substances; animals directly or indirectly absorbed the organic substances produced by plants, and finally animals and plants after their death are decomposed by the influence of certain bacteria into inorganic substances which, taken up again by plants, are transformed anew into organic matter, and so on.

It is the corpuscles of chlorophyll which enable plants in the presence of light to form organic substances from carbonic acid, water, and certain salts. It is on the other hand from the vegetable kingdom that all animals have to derive all the organic matter that is to form their bodies and support their life. It follows that in any large territory the quantity of organisms is regulated by the condition that the total mass of consuming animals has to remain inferior to the mass of producing plants. Unless this condition is fulfilled, a part of the animals must suffer hunger or even perish. For the same reason among terrestrial animals the mass of carnivores must be inferior to that of the herbivores.

But the plants can not perform the important function that devolves upon them—the formation of organic substances—unless they find the inorganic matter which is indispensable to them, and which presents itself under the form of combinations of at least eleven or twelve known chemical elements. If but a single one of these nutritive substances is wanting the plant will not grow. In case of insufficiency the plant just manages to exist; while if there is superabundance it grows rank. The growth of plants depends upon the quantity of nutritive matter they get, and there is an indispensable minimum for each species. The discovery of this fundamental law is due to Liebig, the founder of agricultural chemistry.

Generally speaking, the production of vegetable substances depends upon the quantity of nitrogenous inorganic compounds in the soil. We know that manures rich in nitrogen extraordinarily augment the vegetable production, although this can not surpass a certain maximum characteristic of each kind of plant, beyond which all increase of nitrogenous matter acts as a poison.

Inorganic nitrogenous compounds appear in three forms in nature—those of ammonia, nitrates, and nitrites. Since no plant can grow unless it finds inorganic nitrogenous compounds in its neighborhood, and since the life of animals depends on that of plants, it follows that all the life on the globe depends absolutely upon the existence of these nitrogenous compounds. It is, therefore, of the first importance to follow closely the cycle of transformations of nitrogen in nature.

We know only three sources of the three kinds of nitrogenous compounds which interest us. In the first place, all living beings contain nitrogenous substances, notably albumen, and these are in part eliminated during life as residuary products (urine, etc.), and for the rest are decomposed by putrefaction after death. The albuminoid substances are then transformed into ammonia, which in its turn furnishes nitrites and nitrates, so that the nitrogen is brought back to a form in which it can be used by plants in a new production of albumen. All the processes of putrefaction by which animal carcasses and vegetable remains are transformed into carbonic acid, subterranean nitrogenized waters, and other inorganic substances, are due exclusively to certain definite bacteria. If these are not present or do not meet with the conditions of life which they require, putrefaction is adjourned and with it the utilization of the nitrogenous matter of dead bodies by living ones.

Nor is the decomposition of albuminoids the only process caused by bacteria; they are equally necessary for the conversion of ammonia into nitrous acid, and ultimately into nitric acid, and for the reverse changes. A sort of bacterium called a nitrifying bacterium, or nitrobacterium, existing, it would seem, all over the globe, produces the oxidation necessary to transform ammonia first into nitrous and finally into nitric acid, provided there is enough oxygen at hand. The reverse process of reduction is due to another kind of bacterium, called a denitrifying bacterium, which transforms nitric acid into nitrous acid, and this again into ammonia, and finally sets nitrogen free. The final product of this reduction consists of free nitrogen, which, mingling with the air, is lost from the cycle of transformation. With one exception, nitrogen can not be utilized by plants to form albumen unless it is in a state of combination. Thus, though the greater part of the organic nitrogen returns to living organisms, a certain portion of it is lost by the action of the denitrifying bacteria. The quantity of living organisms would, therefore, be gradually diminished were there no other source of combined nitrogen to make up for the loss.

This compensation is furnished by the free nitrogen of the atmosphere, which, under certain conditions, can enter into combination and become available for plants. Combinations of this kind are brought about in two ways—by the action of lightning, that is, of electrical discharges, and by the symbiosis, or mutual parasitism, of

certain plants with certain sorts of bacteria. It is leguminous plants alone, and of leguminous plants only those upon whose nodes certain bacteria live, that can fix the atmospheric nitrogen and use it to make albumen. In the absence of the specific bacteria the leguminous plants lose this property and behave like other plants, as can be seen by cultivating them in sterilized soil. In respect to compensation for losses of nitrogen, the intimate union between leguminous plants and certain bacteria is probably of far more importance than the fixation of nitrogen by atmospheric electricity.

As far as we know, the cycle whose essential steps have just been sketched is performed in the sea as on the land. In water, as on land, plants alone furnish the food; but, since they can not produce organic matter without light, they grow only in the upper strata of the ocean, down to a depth of some hundreds of meters. The marine plants are, moreover, equally subject to the law of the minimum. The analysis of the medium in which they live—that is to say, of the water with the solid and gaseous substances that it holds in solution—will permit the formation of conclusions analogous to those that soil analysis suggests for terrestrial plants. Moreover, as well as we can judge from recent observations, nitrifying and denitrifying bacteria play important parts both in fresh water and in the ocean.

The three nitrogen compounds of which we have spoken, together with all their salts, are particularly soluble, and, consequently, rains carry off a part of the compounds of this kind. The water thus charged with ammonia and nitric acid flows off by the ditches and brooks to the ponds, lakes, and water courses, and ultimately reaches the sea. The land is, in that way, continually being robbed of a certain quantity of nitrogen compounds, to the profit of the sea. The loss thus sustained by the soil is made up by the formation of new quantities of nitrogen compounds, due in small part to the action of storms, but, probably, chiefly by the intervention of bacteria living in the nodes of leguminous plants.

One naturally expects to find in the sea an animal and vegetable life far more intense than on land, for the reason that the sea, in the course of time, must have been extraordinarily enriched with nitrogenous substances. Indeed, it seems that the incessant bringing of such substances ought, after some hundred thousands or millions of years, to have poisoned the sea and rendered life there quite impossible. Yet, in point of fact, we neither find that life in the ocean has been cut off, nor do we meet there any very extraordinary wealth of living organisms or of nitrogen compounds. On the contrary, the few observations made enable us to declare that sea water does not contain so much combined nitrogen as earth does. This apparent contradiction may, in the present imperfect state of our knowledge, be supposed to be explicable by the action of denitrifying bacteria. From this point

of view, the differentiation of the different kinds of bacteria which take part in the processes of putrefaction in the sea, the study of their modes of action, conditions of existence, and propagation will be of great interest.

Besides a general knowledge of the cycle of transformations of matter, we need the knowledge of the composition and transformation of the plants and animals that we have to study and of the action upon them of their environment in order to comprehend the phenomena of nature and to solve the practical questions to which they give rise. It is needful, also, to at least determine the importance of the commonest species.

Practical agriculture has gained great benefit from investigations of this sort and from results obtained in regard to the relations which exist between the many factors of the question.

Advantages have also been derived from many conquests of science for the utilization of ponds, and it may be hoped that the same principles applied to marine matters will lead to a more complete utilization of the products of the sea. The object of cultivating the soil is to obtain with the smallest possible expense and least work the greatest product. Efforts tend to augment the fecundity of the soil by such a study of the causes of that fecundity as permits the elimination of harmful influences. In the same way we ought to endeavor to get from the sea the greatest possible quantity of useful products. For that purpose, the first thing to be done is to make an exact inventory of the real product of the ocean, or only of a particular, part of the sea, compared with what is furnished by cultivated soil. This exact knowledge of the production gives the surest point of departure not only for a rational exploitation of sea fisheries, but also for a study of the causes of production and of the transformations of matter in the bosom of the ocean.

There are exact statistics of agriculture. Thus we know that in Germany an acre of meadow yields on the average 1.4 short tons of hay. In order to be able to compare this crop with the product of the same area planted with cereals, or with that of a pond of the same size, we must know the chemical composition of the plants in question, so as to be able to compare the different plants, either directly according to their amount of albumen, of fatty matters, etc., or indirectly according to their nutritive value, determined by special experiments. To ascertain exactly the annual production of flesh per unit of surface is less easy. The most satisfactory method is still that of deducing it from the number of young cattle that can be raised annually upon a suitable area. According to the data collected by Viebahn an acre of cultivated land in Prussia yields 75 pounds of beef per annum. For water, as for land, we can, as Hensen has shown,

try two different ways of ascertaining the yield. We can weigh the fish taken from a pond, and thus determine the quantity of useful flesh produced per acre per year, or we can find the quantity of organic matter produced in the form of plants in a given body of water in a year. The values found for the yield in flesh and for the production of nutritive substances must have a certain ratio which may be ascertained by chemical bacteriological and physical study of the body of water in question from the point of view of its capacity of yield. The product of fish in flesh can be directly determined only in ponds that can be emptied and from which all the fish they contain can be taken. Susta gives extended instructions for doing this in his interesting work on feeding carp. The worst ponds give nearly 11 pounds of carp per year to the acre; but large ponds generally give three or four times as much, while the yield of the small ones is six times as much. Village ponds into which flows manure liquor from farms give a yield running up to twenty times the first number.

The observations made upon the exploitation of ponds furnish some information concerning the causes of the variations of production. Those ponds into which flow either the water from manured land or the drainage of villages are always better stocked and give a better yield. The introduction of nitrogen compounds has thus here, as in the case of the soil, the effect of augmenting the yield very remarkably. It has also been found that the yield can be much increased by giving the fish food rich in nitrogen (grains of lupine, etc.). This food is not in all cases directly assimilated. It seems, on the contrary, that it is first taken by larvæ of gnats, worms, insects, etc., which afterwards become the prey of the fish, or else that the food, by the intervention of certain bacteria undergo a decomposition having the effect of rendering them assimilable by the plants of the pond, these plants being then eaten by small animals which, mixed with microscopic plants, serve in their turn as food for the carp. In any case, experience shows that the conditions of production in a small body of water are by no means unfavorably affected by the presence of manure, but that on the contrary they may be greatly improved in this way.

The simple and sure process of directly ascertaining the production of fish is, of course, no longer applicable when we come to large lakes or to the sea, because it is then no longer possible to take out all the fish. We have, then, to fall back on the best statistics. According to the catch of the fishermen, Hensen has estimated the annual yield of the Bay of Hela (meaning, presumably, the Putziger Wiek, in the Gulf of Dantzic) at 28.2 pounds per acre (31.6 kilos de poisson pour 1 hectare de surface en eau). I have calculated in another way that in the "Haff," at Stettin (l'anse de Stettin), the catch of fish amounts to 90 pounds per acre per year (100 kilos par hectare et par an). On the other hand, Heincke sets down the annual value of the products

drawn from the German Ocean as from 100,000,000 to 150,000,000 marks, and, according to British statistics, 11 pounds (5 kilos) of fish are worth 1 mark (23.82 cents, or $2\frac{1}{6}$ cents per pound). Consequently the total catch of the German Ocean would be from 1,100,000,000 to 1,650,000,000 pounds, or from 8 to 12 pounds per acre, worth $17\frac{1}{2}$ to $26\frac{1}{4}$ cents.¹

This production is very low, as compared with that of fish ponds. In the latter the catch may give some idea of the production, but at sea the fishermen only keep such fish as are profitable and can generally only take a part of the fish. The real production of the German Ocean is, therefore, quite unknown. It is true that in a fish pond or field the greater part of the parasites can be destroyed, while in the sea we can not prevent the concurrence of creatures which, though they are not worth catching and transporting (if they are of any value at all), nevertheless draw their food from the general store. Still, I think it highly improbable that the actual catch in the German Ocean represents more than a small fraction of the real useful production. We can only say that if the fishermen take all that could be taken the proportionate production of the German Ocean is not a third of that of the worst class of fish ponds. Besides, the best statistics of fisheries give but rough approximations, having rather a relative than an absolute significance, so that it is quite likely that the catch is much greater than the statistics show. In the case of the "Hafen" of Stettin, careful verification showed me that the actual catch was between two and one-half and three times as great as the statistics showed. It may be that the statistics of the German Ocean are nearer the truth, yet it is certain that they do not include all the products of the sea. For example, the enormous masses of seaweed that are thrown up upon the shores by storms and are then utilized by farmers are not taken into account.

It would be desirable that each year all the fish should be taken from the sea that it can naturally produce, and it would be interesting to know how much this is, in order that we may take all that can be taken without inconvenience to future production.

Hensen has proposed to deduce the quantity of fish from the number of eggs deposited in the spawning season. For the majority of species of useful fish these eggs do not sink, but float, so that the motion of the water, whether by currents or by wind, assure their being pretty uniformly distributed. By making dippings with a fine net it is easy to ascertain the number of eggs and larvæ contained in the vertical column of liquid of a given base, and by operating in this way over an important body of water a great many times every day, so as to correct contingent errors and possible variations, one will certainly

¹ 500,000,000 à 650,000,000 de kilos par hectare, ou 9 à 13.6 kilos, représentant une valeur de 1.8 à 2.7 marks.

succeed in gaining a tolerably exact idea of the distribution of eggs, and consequently in acquiring practically important knowledge concerning the situation and extent of the places preferred by the fish for laying their spawn. These experiments will also furnish valuable data in regard to the quantities of eggs laid by each kind of fish. It is even possible to pursue quantitative experiments, showing the loss at each period of the development of the larvæ. Knowing the quantity of eggs which each species of fish can give, we can finally deduce from the figures furnished by these soundings the quantity of fish really existing in the waters under study at the spawning season. The comparison of the figure so obtained with the statistics of the fisheries will give the ratio between the fish taken and the annual increase.

This method is the only one hitherto proposed which permits us to get an exact idea of the situation. It has thus far only been applied to the fisheries of the Kieler Bucht (la rade de Kiel) in the Baltic and of the German Ocean. These applications have shown that the method is correct in principle and reliable in its application. New observations, however, on fish eggs and their development are yet needed to give the process an absolutely certain basis. These observations are, moreover, indispensable in order to elucidate a number of important, practical, and scientific questions. A quantity of isolated experiments, hitherto of no particular consequence in default of any general principles by which they might be interpreted, become to-day indispensable bases of further researches.

The animals which inhabit the sea are developed in proportion to the quantity of their food. Now, since all this food comes directly or indirectly from plants, it follows that we can just as well estimate the real production of animal life in the water by means of the annual yield of vegetation as we can estimate the product of a farm by the quantity of grass and fodder that it affords. The vegetable produce of the sea belongs to two forms markedly distinct. On the one hand there are the multicellular shore plants of some size, such as fucus or wrack, sea lettuce and green seaweed generally (algues vertes), dulce and other florid seaweed (algues rouges), and kelp (herbe marine). On the other hand there are unicellular organisms so small that with a very few exceptions, they are not distinguishable by the naked eye. The large plants are all collected into a narrow band along the shore, while the microscopic plants are not only found on the border and at the bottom of shallow arms of the sea, but constitute an essential part of the plankton which floats freely in the water. Ideas of the relative importance of the two classes as food are widely divergent owing to the insufficiency of observations hitherto made upon the subject. But if we consider the ocean as a whole, it can hardly be doubted that the quantity and consequently the direct importance of fucoids, florids, and algae generally is very feeble as contrasted with that of

the imperceptible plants which multiply in the free water. The shore alone is bordered by a belt, sometimes quite a meager one, of large plants which, beyond this belt, hardly grow except in shoal water, for the deeper we go the more scanty we find this vegetation.

Suppose the land had no vegetation beyond a similar zone along the coasts. Is it not evident that it could feed but a very small number of large animals? But to render the parallel perfect it would be necessary to suppose the desert surface of the continent more than twice as large, for the ocean covers more than two-thirds of the surface of the globe. The comparison would be rendered still more unfavorable by the fact that at least on German coasts the living marine plants in question are eaten only by a relatively small number of small animals.

But it is not necessary to dwell upon the matter, for it is clear that the food of the animal world of the sea has to be assured under another form.

The tangles and the bottom of the shallows are covered with plants extraordinarily small, nearly comparable to the green algae which clothe the branches of trees, or to mosses. These small plants of rapid growth are much more quickly devoured than the great bundles of fucus (varech) or of laminaria (herbe marine) hard as stone. To make the parallel good it would be necessary to imagine the whole body of the continents to be covered with a thick carpet of verdure, for nothing like sandy deserts or mountain solitudes where but a few animals can maintain a precarious existence are to be found in the ocean. There is vegetation everywhere, and Schütt has well said that the sailor who fancies he has pure water under him really sails everywhere, even in the blue ocean, in the midst of a rich vegetation. At the same time, this vegetation feeds such an extraordinary number of animals that it always appears to be scanty, because the vegetable substances newly produced are devoured as fast as they are produced.

From the point of view of food for animals there is the same difference between the two categories of marine plants as in our latitudes there is between trees and the soft plants of the fields. Like the trees, the fucus (varech) and the laminaria (les herbes marines) take a great development because they are little interfered with (gênés). They strike the eyes more, but in reality it is the meadow which provides food for the herds, meager as it looks. In respect, however, to the conditions under which they are found, the fields of the ocean differ from the fields of the land. The former grow plants of the size of the smallest grains of dust distributed through the upper strata of the sea, and prospering the better for being so regularly distributed. This regularity is assured by the incessant stirring of the ocean, and if any irregularity were to occur it would soon disappear, for if the vegetable organisms are relatively few at any one place they will thereby be enabled to utilize the light and the food so much the more to their

advantage, so that their development will become more rapid; and besides, where there are fewer vegetable organisms animals will be less attracted, and consequently the destruction of them will be less.

Like the microscopic vegetable organisms the animalcules that live upon them are in general regularly distributed over the face of the waters. This is true especially in the open sea, for inshore the wind, the currents, and the possibility of using a different food often come in to modify the distribution of the greater animals. These modifications are still greater at the spawning season, because the fish then collect together. At this season certain kinds of fishing may become profitable which at other times has to be given up on account of the dispersal of its objects.

The regularity of the distribution of the little organisms in sea water led Hensen to the notion of applying to the determination of the vegetable production a process analogous to that used for producing eggs. The method of studying plankton quantitatively which Hensen invented and perfected for the purpose mentioned is of great importance for all biological investigations on the sea. The fundamental idea of this method is that it is proper to bring back to a single point of view all the observations on the influence of the conditions of the sea and on the mutual relations of marine organisms; on the transformations of matter and the chemical constitution of marine substances; on the quality and quantity of vegetable and animal organisms living in the water. In the first place it is necessary to collect, as far as possible, all the plants which are found under a definite area of the surface of the water. To do this, Hensen proposes the use of nets with very narrow meshes, by which a vertical column can be, so to speak, filtered, and make a statistical statement of the organisms so lifted. Unfortunately the finest nets now obtainable allow the passage of the microscopic vegetations which sometimes appear in important masses in certain regions. Hence it would be necessary to invent for those excessively minute organisms special methods of quantitative analysis. However, Hensen has obtained interesting results. Each drawing of the net represents the total organisms of the plankton down to a size of at least 0.048 mm. that at a given time and place are contained in a vertical column of known dimensions. By reason of the regularity of distribution of the organisms the results can, moreover, be extended to considerable areas—hundreds of square kilometers of open ocean—over which the conditions of life are uniform. Near the coast and within currents the conditions are different; so that it is proper there to take samples at lesser intervals. Furthermore, in order to gain a close acquaintance with the plankton of a body of water, it is necessary to repeat the experiments at the shortest intervals of time possible during at least a year.

It is not enough to measure the volume of organisms collected. It is

necessary to estimate the number of individuals of each sort. Although this counting involves great expenditure of time, it is quite indispensable to the ascertainment of the production. It is necessary, in fact, to separate the producers from the consumers. It is proper, also, to take into account, at least for the principal species, the rapidity of increase, the duration of the different stages of development under the various conditions of life, the mode of alimentation and the needs of the principal animals. The results of the drafts taken at the beginning of the year may be regarded as a principal sum of money, of which the interest is spent in the course of the year, the capital remaining at the end about what it was at the beginning. The comparison of the quantities of animals of each sort and size in the successive drafts, together with the knowledge acquired by direct observations of their alimentary needs, enable us to infer whether the consumption is really sufficient to absorb the annual vegetable production. This comparison requires a very large set of drafts, because the rate of augmentation of the different species depends upon the conditions of life, and consequently varies from one season to another. Finally, the chemical analysis of the principal plants is necessary if we wish to compare the productivity of the sea in organic matters with that of the land.

It has been questioned whether it is possible to acquire an exact notion of the production of a part of the sea by observations of the plankton alone. But the objections which have been made neglect the fact that under natural conditions a body of sea always produces as much as possible, and that in a small body, like the Kieler Bucht, for example, the production in the middle of the water, and even along the coasts out of the light—a production which is the same for the whole surface—depends essentially upon the nutritive matters that the plants find in solution in the water. But in consequence of the incessant stirring up and mixing of the water, there can be no sensible difference between the nutritive matters which are presented to the plants in the open sea and in inshore places. Consequently the attentive observation of the plankton taken up, as has been said, in a particular place during a whole year, furnishes a sufficiently accurate scale of comparison for an estimate of the capacity of production of the whole body considered, whether the production inshore is a little less or a little more than that of the open sea.

Thus far, the method of the quantitative examination of the plankton has been applied to the following marine bodies:

First. In shoal water:

(a) During several years: The Kieler Bucht (possibly the Kieler Hafen is meant).

(b) During all seasons of one year:

In the Arctic zone, the Fjord of Karajak, in Greenland, in latitude 70° N., by Vanhøffen.

In the Mediterranean, at the Straits of Messina, by Lohmann.

In the Tropics, the Roads of Ralum in New Pomerania (formerly New Brittainia), in latitude 4° S., by Dahl.

(c) During the winter months (1888-89):

In the Bay of Naples, by Schutt.

Second. On the high seas, by a series of drafts during the course of voyages of exploration:

In the Baltic (from Memel to Gotland); in the northern part of the German Ocean, from Skagen to the Hebrides; in a great part of the Atlantic during the Plankton expedition (from the middle of July to the beginning of November, 1889); in the part of the sea between the Lofoden Islands and the north of Spitzbergen during the Prince of Monaco expedition, in July and August, 1898.

I shall here leave out of consideration the numerous results which these observations have furnished in zoology, zoogeography, and oceanography, and confine myself to two points. The first is that shallow seas are richer in plankton than deep seas are, and that among the latter the Saragasso Sea is particularly poor (in August). The explanation of this is to be sought in the law of the minimum. In soundings, the influence of the soil and of the land with its contributions is more sensible, and plants find in a less mass of water a relatively great quantity of inorganic substances which, in the depths of the ocean, are more scattered and are specially deficient in the upper layers, where alone vegetation is possible. The substances in the unlighted depths can not be directly used by plants. On the other hand, as the great currents of the ocean extend along the coasts they bring to the upper layers of the high seas new food for the plants, so that these layers may be relatively more productive than the Saragasso Sea, whose waters are still and in the middle of which the conditions of alimentation appear to be altogether unfavorable.

It would be important to ascertain by chemical investigations which of the substances susceptible of feeding vegetation exists in smallest amounts. It is probably combined nitrogen. The results mentioned above, as furnished by fish ponds, lead toward this conclusion. In the same line are the experiments of Apstein on the lakes of Holstein, experiments which I have verified, showing that lakes rich in plankton contain much nitric and nitrous acids, while lakes poor in plankton are also poor in nitric acid, the quantity of plankton and the percentage of nitrates being sensibly proportional.

The second point to which I wish call attention in the results of the quantitative study of plankton—and it is the more striking of the two—is that tropical seas and the temperate zones are relatively poor in plankton, while the Arctic Ocean is rich. On land it is just the reverse. Luxuriant vegetation and superabundance of animal life are

characteristic of the Tropics and mightily contrast with the meager vegetation and sparse population of the polar solitudes; and one would expect beforehand to find the same contrast in marine life. Plants, for example, need light to produce organic matters. Now, tropical seas are better lighted than glacial seas. High temperatures, too, are favorable to the development of marine organisms. Finally, the extraordinary variety of forms in tropical seas seems to argue greater wealth. Without Hensen's methods we should not have suspected the remarkable fact mentioned.

First of all, we must make sure that the results of the Plankton Expedition are correct. This expedition only drew its samples during a part of the year, so that it might be that at other seasons the relative poverty of the tropical seas would be transformed into great wealth. In order to ascertain how much there was in this objection, observations were made on different coasts in very different latitudes during a whole year, while at the same time as many additional observations as possible were made in deep water. We thus find at our disposition numerous observations made in the three oceans at my solicitation, by the Messrs. Schott, of Hamburg; Captain Bruhn, of Bremerhaven, and Naval Surgeons Krämer, von Schwab, and Freymadl. All these observations lead to the same conclusions: The Arctic regions are very rich in summer, while the tropical regions are poor in plankton the whole year round. Conditions specially unfavorable to production appear in the Mediterranean, as in the Saragossa Sea. The single comparison of the curves of volume for the four coast stations where the results have been most accurate confirms this conclusion. If we take the arithmetical means of the monthly values we find that in New Pomerania the mean volume of plankton for the year is double that at Messina, while for the Kieler Bucht it is ten times that at Messina.

How shall we explain this remarkable fact, this bizarre contrast between the production of living substances on land and in the sea? First of all, we must get it clearly in our minds that the development of plants, and consequently their production, depends not only on the illumination, but also and in quite as large measure on the quantities of nutritive substances that are brought to them. If one of these substances, say combined nitrogen, is present only in relatively small amount, the production will suffer from this want. Penury of nitrogen is suggested, not only by the considerations put forth above, but also in a striking way by the fact that, according to the drafts of plankton, the quantity of nutritive substance in minimum ought to depend very much upon living organisms. Even slight differences of temperature have great importance for the quantity of plankton collected, and these differences of temperature affect chiefly the vital

activity of the organisms—for example, of the marine bacteria—while they are nearly without effect upon the solubilities of the inorganic matters which are adapted to becoming food for the vegetation. It thus seems that the cause of the richness of cold waters and of the poverty of warm waters should be sought in the difference of development of the bacteria of putrefaction in the largest sense of the term, and in the influence of these bacteria on the proportion of nitrogenous compounds in the water.

Among these bacteria, the nitrifying bacteria exercise their function in arable soil only at a temperature above about 5° C. (41° F.). In all probability there are in the sea other sorts, nitrifiers and denitrifiers, able to accommodate themselves to other temperatures. Still, in the present state of our knowledge, we may assume that bacteria cease to act at the freezing point, or a little below that point. But if denitrifying bacteria can not perform their function in cold waters, it follows, almost necessarily, that polar seas must be richer in nutritive substances than tropical seas. In a large part of the polar seas the temperature of the whole liquid mass from surface to bottom remains even in summer, near 0° . North of a line extending from eastern Greenland to Norway, through Iceland and the Faroe Islands, the temperature at the bottom is generally below 0° C. South of this line the temperature of the deep waters of the Atlantic is certainly not much higher, because the cold water of the polar seas flows into the deep regions toward the equator. But at 1,000 meters (547 fathoms) the temperature is already 4° to 5° , and for depths of less than 100 meters, as well as along the coasts, it is notably higher, so that the bacteria here find, precisely as in the productive layers of tropical seas throughout the whole year, conditions favorable to their life. In the temperate zones the destruction of nitrogenous compounds is too limited during the winter and it is only in summer that it becomes important. Finally, in the Mediterranean the conditions of life of bacteria are still more favorable than in the Tropics, because a bar across the Straits of Gibraltar prevents the cold water from entering. Hence, even at great depths (of about 4,000 meters), there is always a temperature of 12° to 16° , which explains the development of bacteria in the whole liquid column observed and the consequent striking quantitative poverty in plankton of the Mediterranean Sea.

If we can not dismiss absolutely the idea of a denitrification that can not be neglected in the ocean, it appears to me highly probable, according to the observations hitherto made, that this decomposition of the principal vegetable nutritive substances is preferentially accomplished in warm regions.