THE PLACE OF PHYSICAL OCEANOGRAPHY IN OCEANOGRAPHIC RESEARCH

By

H. U. SVERDRUP

Director, Norsk Polarinstitutt

and

Professor of Geophysics, University of Oslo

Talking here at Woods Hole about the place of physical oceanography in oceanographic research is comparable to carrying coals to Newcastle. In no other locality are gathered so many institutions engaged in marine research, and nowhere exist such unique opportunities for integrated oceanographic research.

Most of us probably know that the initiative to establish the Woods Hole Oceanographic Institution was taken by the National Academy of Sciences, which in 1927 appointed a special committee on oceanography. The mutual dependency of the marine sciences has never been expressed more lucidly than in the report of this committee, which was submitted in November 1929. This report had been prepared by the secretary of the committee, Dr. Henry B. Bigelow, and was published in book form in 1931.

Dr. Bigelow did not claim that his views were novel. They had, for instance, been stated in the first report of the International Council for the Exploration of the Sea (1902), a council which had been formed primarily for the purpose of applying oceanographic research to fisheries problems in the waters of northwestern Europe. It may seem superfluous to speak on a topic which has been dealt with repeatedly during the last 50 years, but I venture to do so for three reasons.

In the first place it seems that the necessity of co-operation between marine scientists cannot be stressed too frequently. It appears peculiarly difficult to achieve close contact between physical oceanographers and marine biologists, perhaps because they have difficulties in talking in terms which are mutually understood. This point was emphasized by Dr. Bigelow who, on behalf of the biologists, wrote: "So the unfortunate biologists, even if mathematics are to them a closed book, as is the case with too many of us, must perforce take as keen an interest as do his physical confrères, in the modern applications of mathematics to ocean dynamics and hold as high an appreciation of them." How difficult it has been to reach this goal is evident from the fact that as late as 1951 the International Council arranged a special meeting devoted to the discussion of the place of physical oceanography, or hydrography as it is called by that body, in fisheries research. It appears, therefore, that no matter how obvious the co-operation between the different groups of marine scientists may be, the need of repeating and, even more, of demonstrating the value of co-operation is still present.

In the second place, I wish to underline the necessity of broad training. Every oceanographer, regardless of how narrow his speciality may be, should have some basic knowledge of the fields of all the marine sciences, partly because he ought to be acquainted with the terminology of his fellow workers and partly because he should be able to recognize results within his own field which have a bearing on problems of others or to know where he may obtain information that has a bearing on his own. I believe this demand for a broad training has been better met in this country than in any other, perhaps because of the rapid expansion of the science of oceanography which has taken place here and which has made it possible to design adequate courses for general training.

In the third place, I am speaking on the place of physical oceanography in oceanographic research because I like to do so. I am convinced, though, that my thinking has been greatly influenced by Dr. Bigelow's book of 1931 because I have not, I regret to say, been raised in an atmosphere of cordial co-operation between the marine sciences. On the contrary, in my own country and probably in most of northwestern Europe there has been a tendency to draw a line between physical oceanography and the other marine sciences, a tendency which may be illustrated by the fact that there the term oceanography is generally limited in meaning to the physics of the sea only. Thanks to Dr. Bigelow I have been convinced of the fallacy of placing one single branch in a separate position.

It is not my task now to deal with physical oceanography as an independent science or to dwell upon its application to other sciences than the marine. Instead I wish to emphasize that, among the marine sciences themselves, physical oceanography is in the unique position of being independent of the other marine sciences while serving as an auxiliary science to these. Conclusions based on studies of physical conditions may be confirmed by findings in other fields, but I cannot recall a single case in which the explanation of observed physical conditions are based on results in, say, marine chemistry, biology, or submarine geology. On the other hand, it is easy to find examples to show that specialists from these fields have to turn to physical oceanography to obtain explanation of observed conditions.

A chemist may say that this is an exaggerated claim and that the development of chemical methods and their application to the chemistry of sea water is an independent science. This, of course, is true, but if the chemist is to account for such features as the distribution of the so-called plant nutrients, such as phosphates and nitrates, he is no longer on his own but has to turn to both biologist and physicist. Let me take an example. Observations show that the upper layers of the sea are generally poor in phosphates and nitrates whereas the deeper layers are relatively rich. For an explanation of this feature it is necessary to consider biochemical processes. The upper layers are poor in phosphates and nitrates because these substances are used by the marine plants in building up organic matter, and the deeper layers are rich because the phosphates and nitrates there are brought back into solution when organic matter is decomposed.

In the Mediterranean, however, both deep and shallow waters are poor in phosphates and nitrates, and for an explanation of this feature it is necessay to turn to the marine physicist. He can point out that a great exchange of water between the Atlantic and the Mediterranean takes place through the Strait of Gibraltar, with Atlantic water flowing in near the surface and a nearly equal amount of Mediterranean deep water flowing out close to the bottom of the Strait. There is every reason to assume that these conditions have existed for such a long time that an approximately steady state has developed, meaning that the amounts of phosphates and nitrates that are carried in and out must be equal. Since the inflowing water is mainly surface water, it has a relatively low concentration of phosphates and nitrates, while the outflowing deep water also must be poor in the same substances. Similar considerations account for the fact that waters of the North Atlantic Ocean contain less phosphates and nitrates than those of the South Atlantic.

Turning to problems in marine biology, it is evident that physical oceanography is an indispensible auxiliary science in the field of ecology. Instead of expanding on this subject in general terms I wish to present a few specific examples.

The environment, as represented by the physical and chemical characteristics of the waters, is of immediate importance to the primary productivity of the different ocean regions. Observations which were undertaken regularly at weather ship "M" during the spring of 1949 throw light on some salient features. Weather ship M is located at 66° N, 2° E. Gr., i. e., in such a high latitude that the light during winter is too weak to permit any production of phytoplankton. The question then arises as to when one may expect the vernal blooming of phytoplankton to begin. When tackling this

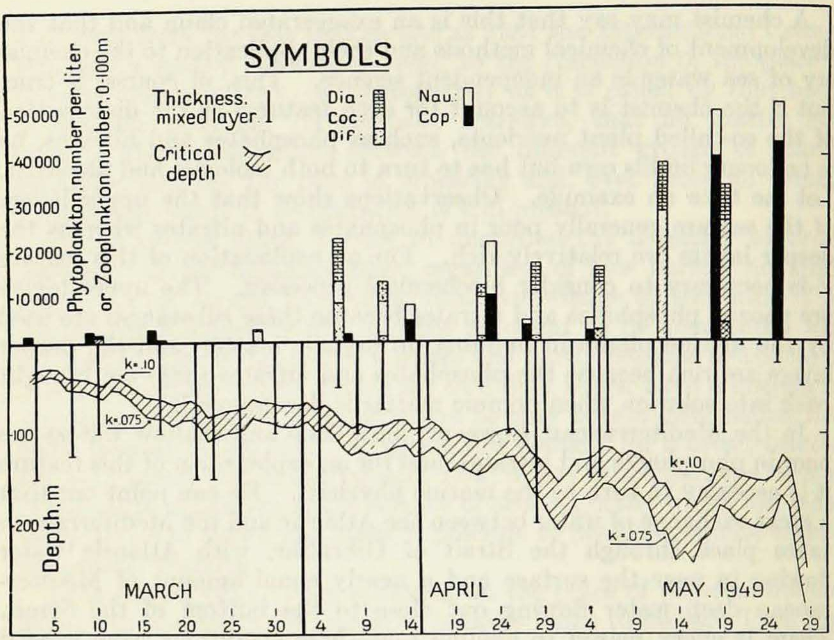

Figure 1. Results of observations at Weather Ship "M" (66° N, 2° E Gr.). Dia, Diatomaceae; Coc, Coccolithophoridae; Dif, Dinoflagellatae; Nau, Nauplii; Cop, Copepods.

problem one must bear in mind the fact that in these northern waters there develops during winter a thick, well mixed surface layer which, because of winter convection, is rich in plant nutrients. Gran and Braarud have suggested that production by photosynthesis cannot exceed destruction of organic matter by respiration if a deep mixed top layer exists. They reason that the plankton organisms within a well mixed layer are about evenly distributed; production takes place in the daytime only and near the surface where the light intensity is sufficient, whereas destruction takes place both day and night and evenly within the entire mixed layer. The total plant population cannot increase if destruction exceeds production. This implies that there must exist a *critical depth* such that blooming can occur only if the depth of the mixed layer is *less* than the critical depth.

With certain assumptions, particularly those concerning the extinction of light which travels downwards in the sea and the light intensity at the compensation depth, it is possible to compute the critical depth. The results of such computations pertaining to conditions at weathership M during March, April and May 1949 (see Fig. 1, lower part) show that the critical depth increases as the season advances; that is, it increases as the intensity of the incoming radiation increases. The increase is irregular because of varying cloud cover. The critical depth is shown not by a single curve but by a band, because the exact value of the applicable extinction coefficient is not known. In Fig. 1 the varying thickness of the mixed layer is also shown by vertical lines which are entered for the days on which observations were made. On 7 April the thickness of the mixed layer was for the first time less than the critical depth, and only after the beginning of May did it become systematically smaller. The effect of intense surface heating, leading to formation of a very shallow mixed layer (stabilization), did not appear before mid-May. If our reasoning is correct, these features imply that the phytoplankton population should be expected to remain insignificant until the beginning of April and that a moderate blooming should start at the end of the first week of April followed by an intense blooming in the second week of May. The recorded amounts of phytoplankton which are shown in the upper part of Fig. 1 confirm these conclusions. These plankton collections also reveal that, simultaneously with the blooming of the phytoplankton, the number of copepods and nauplii increased. After the middle of May the copepods became so numerous that the increase in the phytoplankton population undoubtedly was checked because of grazing.

This example appears to demonstrate that the spring blooming of phytoplankton in high latitudes depends in a well defined manner upon the physical-chemical conditions of the surface layer, but unfortunately we have only an isolated example at hand, and the good agreement obtained may be fortuitous.

Next let us turn to a much more general problem, that of the relative productivity of different ocean areas, where by productivity we will understand the total amount of carbon that is fixed below each unit area of the sea surface. Assuming that productivity depends on the rate at which the plant nutrients of the surface layers are renewed and that the renewal takes place by physical processes, such as vertical convection, upwelling, and turbulent diffusion, it is possible to indicate roughly where large or small productivity may be expected (Fig. 2). Regions of high productivity should be found in high northern latitudes where winter convection operates and in lower latitudes where upwelling takes place, either along coastlines or in localities associated with diverging surface currents. In the Antarctic, high productivity should be expected because, in connection with the general circulation, deep water rises toward the surface. Moderate productivity can be expected in the vicinity of most coasts and at the boundaries of strong

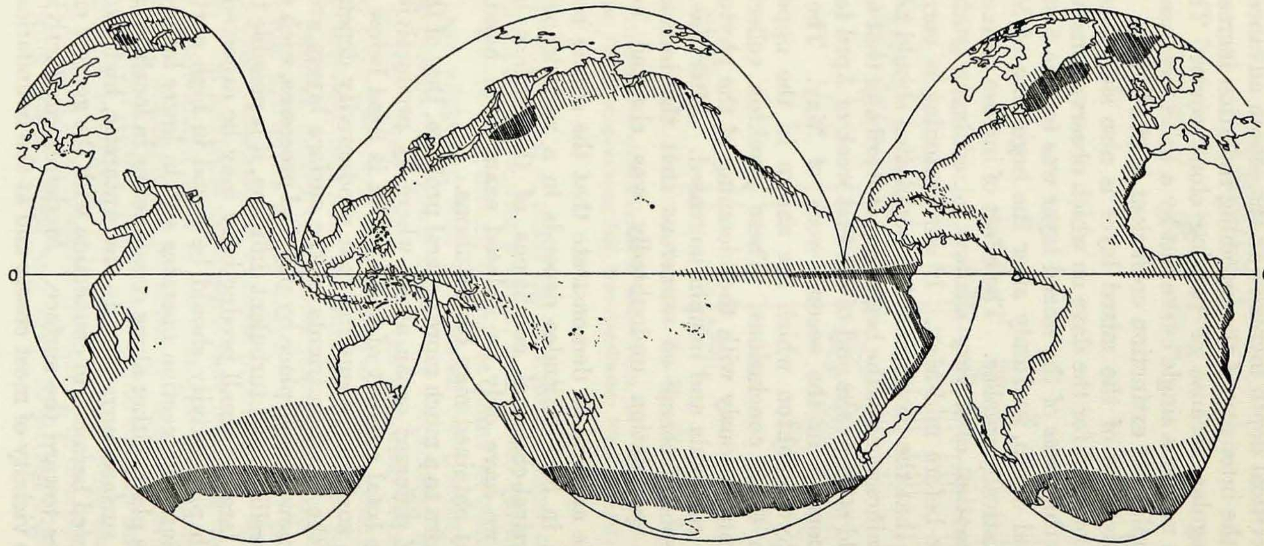

Figure 2. Schematic representation of the probable relative productivity of ocean areas. Heavy shading indicates very productive areas, light shading moderately productive regions.

currents where irregular vertical motion may take place in connection with temporary disturbances. In lower latitudes the run-off from land after torrential rains may also be of great importance to the productivity of the coastal regions. On the other hand, low productivity is to be expected in lower latitudes in the central areas of the oceans where a renewal of the plant nutrients in the surface layer takes place mainly by decomposition *in situ* of organic matter or by slow diffusion from below.

As yet it is not known if these conclusions are valid. They are based on knowledge of the physical-chemical picture, but they assume that a net transport of plant nutrients to the photosynthetic zone is necessary in order to maintain a high productivity.

So far I have dealt only with features pertaining to the primary productivity of the sea. In these cases the relationships should be expected to be realtively simple, because the fixation of carbon is directly dependent upon the amount of light present in the surface layer and upon the available chemical substances; that is, it is dependent upon physical and chemical conditions. Different species of marine plants may react differently to the prevailing conditions, but in principle we have a relationship that can be fairly well defined. The situation is much more complicated when we turn to the animal populations of the sea. The distribution and behavior of the animal groups depend not only upon the generally unexplained reaction of animals to their physical surroundings but also upon their reaction to the biological environment in which they live. The higher up we go on the scale, the more complicated do the interrelations become, for which reason it is often difficult if not impossible to establish any clear-cut connection between the physical environment and the behavior of fish. However, certain more or less trivial relationships exist between the distribution of marine animals and the physical environment. I am thinking of the fact that the distribution of most species is related to temperature conditions; thus climatological charts of the oceans, representing average temperatures of waters and so on, also indicate the distribution of such species. Similarly, in recent years the occurrence of southerly species off northwestern Europe is associated with the temperature increase of the water during the last 25 years.

Explanation of these features is in the hands of physiologists and biochemists, but knowledge of the relationship of organisms to their physical environment can in some cases be used for forecasts of commercial value to fisheries. Let me take one example that is based on work by Dr. J. Eggvin, physical oceanographer at the Directorate of Fisheries, Bergen, Norway.

Off the coast of northern Norway there is a layer of coastal water which has a lower salinity than the Atlantic water and which in winter also has a lower temperature. Below the layer of coastal water lies a transition layer within which the temperature in winter is 4 to 6° C. In late winter when the cod enters the Lofoten region for spawning, it is found in this transition layer. Therefore the depth at which the cod is encountered depends on the thickness of the well mixed upper layer of coastal water. When this layer is shallow, the cod is found close to the coast and in relatively shallow water, but if the upper layer is thick, the cod is found at greater distances from the coast and at a greater depth. In the former case the fishing is easier and simpler than that in the latter, and the yield from the fishing effort therefore depends on the structure of the water masses. Eggvin has been able to show that the thickness of the top layer depends upon such factors as precipitation, run-off and air temperature during autumn and early winter, and in some instances he has been able to issue forcasts of considerable economic value.

I shall confine myself to a presentation of these few examples (one being hypothetical) of relationships between the physical-chemical environment and the organisms. I know that most of you could easily enumerate many more.

To submarine geology, physical oceanography is an important auxiliary science, particularly when dealing with many problems in sedimentation. Let me mention that in November 1953 I met for the last time the late Professor V. Walfrid Ekman of Sweden, the Nestor among physical oceanographers. In his 79th year he had just published an exhaustive discussion of observations of currents which he had conducted with Helland-Hansen in 1930, but he had no intention of slowing down. He told me that he had become very much interested in the density currents which may explain the occurrence of layers of sand between layers of fine sediments at great depths and in basins and that he now planned to start a study of these currents. Others will have to do so now.

In conclusion I wish to return to the question of why it has been so peculiarly difficult to establish more intimate co-operation between specialists within the different marine sciences and why teamwork has been slow in developing within oceanography. I believe that the fundamental reason lies in the fact that, until recently, each specialist has had a limited and specialized training. I hope that this convocation in these surroundings with the most outstanding facilities for integrated oceanographic research will not only stimulate co-operation but will also stimulate efforts toward broadening the training of all students of oceanography.