CHAPTER VI

ECONOMIC VALUE OF OCEANOGRAPHIC INVESTIGATIONS

THERE is hardly an aspect of oceanography but affects one or another phase of modern civilization; and naturally so, for this science is concerned with the physical and biological economy of some seventy-one per cent of the earth's surface.

When oceanography is considered from the severely practical standpoint of human economics, a distinction must be drawn between the study of such oceanic phenomena as exercise a basic control over the habitability of the lands, and of such others as man can turn to his benefit by his own efforts, but which will neither serve nor harm him otherwise. The first category includes the general influence that the oceans exercise on the climates of the continents. The second covers all the ways in which man can draw raw material for his use from the sea; also it covers the knowledge he needs to make the latter a safe highway for his commerce. It is with this second category that we are now concerned.

Food and safe navigation are now, as they have always been, man's most urgent demands from the sea. Therefore, the lines of oceanographic study from which the most direct economic advantages may be hoped at present are those having to do: (1) with the biology of the animals that support the commercial fisheries; (2) with the various events in the sea that affect navigation, and with the contour of the bottom from this same standpoint. In fact, it has only been as knowledge has increased with the progress of civilization, that greater and greater utilization of the biologic resources of sea (fisheries) has become possible, and that navigation has been made reasonably safe. The study of the characteristics of coastwise currents, as affecting harbor construction, and so forth, along sandy shores, and a more detailed exploration of the contour of the bottom to make easier and cheaper the construction of submarine cables may conveniently be discussed in connection with the navigational aspect, the technical procedure being similar. Investigation as to whether the relationship that the temperature of the sea water and its circulation bears to the temperature, pressure, and circulation of the overlying air, can be made to afford a basis for long-range forecasts of climatic variations, is also an economic problem now to the fore.

Other subjects less promising of immediate commercial advantage, but which may eventually lead to useful developments, include: (1) chemical studies to test the possibility of profitably extracting from the total sea salt, that has so long been an important object of commerce, or from sea water direct, the many other substances that it contains beside sodium chloride; and (2) attempts to derive power from tides, waves, thermal contrasts, and so forth. At present the problems involved under these headings are more technologic and economic than oceanographic; nor is it possible to foresee how rapidly — if at all — the exploitation of the sea will develop in these directions. The following discussion of the economic value of sea science is therefore limited to the marine fisheries, to circulation and depth of water as affecting navigation and the other matters mentioned above, and to oceanography as a possible adjunct to long range weather forecasting.

1. The Sea Fisheries

Much has been written of late about the total productivity of the sea, and the fact that this may be greater (per unit of area) than that of the land has been emphasized repeatedly. But under present conditions of civilization the great majority of the species of marine animals and of marine plants must be left out of account as promising sources of human food. And even if economic pressure should finally drive the white races to turn to such unfamiliar sources as sea urchins, holothurians, or seaweeds, for important additions to the food supply — all of these are eaten, more or less, in various parts of the world — it is safe to predict that the land will always be the chief source for human food, at least for as long a period as it is worth while to be concerned with the future course of events.

It is not necessary, however, to credit the sea with any fanciful possibilities in order to bring out the great importance that the fisheries have always played in human economy. Each year man draws an enormous amount of human and stock food from fishes, crustaceans, mollusks, even from seaweeds; also oil from fish as well as from the blubber of seals and whales; glue and fertilizer from fish scrap; and pearl essence from scales; while the manufacture of leather from shark skin is an industry that may reach considerable proportions if a dependable supply of raw material can be made available. The increasing pressure of population upon agriculture on the land makes the expansion and proper conservation of the harvest of the sea every year a more pressing problem, for the demand for more complete utilization of the resources of the fisheries grows more insistent.

We must assume that this pressure, not only on the resources of the Atlantic, but of the Pacific and Indian Oceans as well, will continue and become more intense. For as population multiplies in the countries bordering on those seas, fisheries will correspondingly advance in efficiency of method, and an intensity of effort, extending at the same time farther and farther afield to regions where the supply has hardly been tapped as yet.

The following statistics may make the economic value of these products of marine animals and plants more concrete. The sea food, for example, taken in an average year within the confines of the Gulf of Maine (comprising the 200-mile sector between Cape Cod and the Scotian Banks) amounts to about 500,000,000 pounds, or enough to give one hundred pounds, more or less, to every inhabitant of the New England States and of those parts of the Maritime Provinces of Canada that border on this sector of the sea. The fisheries of California on the opposite side of the continent yield about 600,000,000 pounds annually. The annual catch of food fishes off the Atlantic coast of the United States is 700,000,000 to 800,000,000 pounds; of fish for oil and fertilizer about half as great: of shellfish (without the shells) more than 140,000,000 pounds. The combined yield of the fisheries of the United States and of Canada is about 3,300,000,000 pounds annually, worth more than $100,000,000 to the fishermen. The catch of cod alone in the western North Atlantic has averaged annually about 1,100,000,000 pounds for the past forty years. As long ago as 1912 the value of the fisheries of the countries of northwestern Europe was about $135,000,000. The annual world yield of aquatic products (most of it marine) is more than 27,000,000,000 pounds in weight, and more than $1,000,000,000 in value. Surely, an industry of this magnitude deserves the most intelligent management possible.

Correct management in this case must be predetermined by the fact that most of this vast supply (chiefly utilized as human food, but also including important by-products), is a truly natural resource, as contrasted with the yield of agriculture on land; man has nothing whatever to do with its production or support, but merely takes a part of the wild crop that the pastures of the sea nourish. It is true that numbers (that seem enormous by any absolute standard) of sea fishes have been and are artificially propagated and returned to the sea every year, but it is doubtful if these efforts have had any appreciable effect on the stock of any important commercial marine species; this is recurred to below (page 201). And while shellfish are cultivated to some extent, this industry is in its infancy. The sea fisheries are thus more nearly on a par with forestry than with agriculture; and the methods of management, to be successful, must conform more nearly to the procedure followed in a forest where natural reproduction is depended upon to maintain the supply, than to the management of any cultivated crop.

We see a measure of the productivity of the sea pastures in the fact that while no wild crop on land, plant or animal, can long withstand intensive harvesting unless replaced by human effort, men still fish for cod on the Grand Banks as successfully as did the fishermen who first ventured to the shores of Newfoundland for that purpose.

Vast, however, though the supply of fish and shellfish be, fishermen have long appreciated that the stock of fishes in the sea is not unlimited; the rapid disappearance of whales almost to the point of extinction, when they are hard-hunted, is a warning. And greatly though the extent of the oceans exceeds that of the lands, all the great fisheries (except for whales) are confined to a comparatively narrow belt, along the shelves and slopes of the continents; also to comparatively shoal water. On the American side of the North Atlantic, for example, the outermost of the productive fishing grounds lie only about 250 miles out from the land (off the shores of Newfoundland). And the grounds or banks on which the important commercial species are plentiful enough to support profitable fisheries occupy only a fraction of the area between the coastline and the continental slope that marks their offshore boundary. In the deeps outside the latter no great fishery has ever been developed, nor is there any hope of such. The case is similar on the opposite side of the North Atlantic. In fact, the whole basin of the North Atlantic outside the 1000-meter contour is barren from the fisheries standpoint. Nor is this barrenness due to distance from land or to the difficulty of fishing at great depths, but to the fact that, in spite of the long list of fish species that people the ocean basins at all depths, these are few in individuals compared to the population of the inshore grounds, while most of the oceanic species are small.

Consequently, there is no reason to hope that any true deep-sea fish will ever support an important fishery, or that great fisheries will ever be developed in the North Atlantic much farther out from the land than at present.

In the South Atlantic, Pacific, and Indian Oceans a still smaller part of the total area offers commercial fishing possibilities than in the North Atlantic. In short, only a small fraction of the total area of the sea supports practically all the fish species (and individuals) from which mass production of human food, or of other useful products, can be hoped. The whale fishery alone leads out into the high seas far from land, and no increase in the yield can be expected from that source: on the contrary, how to maintain the stock of whales in the face of even a moderate kill, not how to utilize them more fully, is now the crying problem.

The past quarter-century has seen a rapid increase in the intensity of fishing in the North Atlantic, in response to the increasing demand for fish, favored by more effective methods of harvesting the catch, by improved transportation, and by better systematized marketing. For all these reasons the demand for sea food and for the by-products of the fisheries (oil, soap, fertilizer, leather, and so forth) will continue to increase; to meet this increasing demand the stock of herring, cod, haddock, halibut, lobsters, and the rest will be subjected to a more and more intensive drain. The intensity of the British steam trawl fishery, for example, increased by 11 per cent from 1913 to 1920. A multiplication in the number of large steam otter-trawlers sailing from the ports of New England from 32 in 1924 to 64 in 1929, and increase in the catch, by this particular fishery, from 47,000,000 pounds to 119,000,000 during this same interval, illustrate the corresponding increase in the amount of fishing that is yearly done in the American side of the Atlantic, with more and more efficient gear. And wherever, in the sea, fishermen can catch their fares, the story will soon be the same, if it is not so already.

Under these circumstances, the questions immediately urgent of solution with regard to the marine fisheries are: (1) How much fishing can each species now the subject of commercial exploitation stand without depletion at the hands of man? (2) What measures of regulation should be taken to prevent depletion when danger of the latter seems imminent, or to restore a depleted stock? (3) What is the possibility of extending the fisheries to new grounds? (4) What hope is there of marketing kinds of fish, or other marine products, that are not utilized at present? (5) Can we find a rational basis for predicting in advance the great fluctuations in the abundance of fishes that are known to occur from natural causes, so as to order our fishing efforts more economically?

There has been much discussion as to the degree to which the commercial fisheries have depleted one or another species. Different meanings associated with the term 'depletion' have also caused misunderstandings. If we use it in the sense of reduction, in numbers, of a species to the point when the fishery for it has seriously suffered, this is in fact a danger to be reckoned with in particular cases.

The history of the fisheries includes sundry examples not only of the whales as just mentioned but also of certain fishes, crustaceans, and mollusks that have been fished down to a point where intensive pursuit is no longer profitable on grounds which had yielded abundant fares when first exploited. The halibut of North American waters perhaps affords the most spectacular example of this. Thus, the annual catch brought in by the New England fishermen from the Banks off the Gulf of Maine, off Nova

Scotia, and to the north and east in the Atlantic, fell from about 15,000,000 pounds in 1879, to 3,000,000 pounds in 1926. In the North Pacific, too, it is certain that a decline in the catch of halibut on the older grounds from nearly 300 pounds per unit of gear in 1906 to less than 50 pounds in 1926, and the fact that no more fish are now taken off an 1800-mile stretch of coastline than were formerly caught along 600 miles, has directly resulted from overfishing. The speed with which an overdrain on the stock is reflected in the fishery for the halibut may also be illustrated by the fact that newly developed grounds in the Pacific that yielded 160 pounds per unit of gear in 1923, yielded only 100 pounds three years later, and less still in 1927.

It is generally believed that the great decrease in the catch of albacore off California also reflects too intensive fishing. Similarly, the striped bass has been practically exterminated on parts of the New England coast, though holding its own better along the more southern shores of the United States; the smelt of the northwestern Atlantic fails to hold its own; along certain sectors, European and American, the catch of lobsters per unit of effort has greatly declined since early days, as is also true of the abalone along the coast of California.

Commercial developments on land may also damage the fisheries near shore. The effect, on shellfish beds, of pollution either by sewage or by industrial wastes is often serious; sometimes directly, sometimes indirectly, as when the oysters or clams are contaminated with the bacteria of human diseases. The damming of tidal estuaries may also have a destructive effect, not only within the basins so created, but by altering the circulation of water in the general vicinity. In fact the probable effect of one project of this sort on the 'sardine' fishery for young herring in the region of the Bay of Fundy (a $2,000,000 industry, based on one of the most important local fisheries of the Atlantic coast of North America), is now causing concern to the fisheries services of Canada and of the United States, for want of the detailed understanding of the biology of the herring, and of the hydrography of the region that is needed for positive prediction.

However, almost all of the clear cases where commercial fishes, or shellfish, have been seriously reduced in numbers have been of species living so close to the land that they are especially vulnerable: the majority of fishes involved are species that enter fresh water at some time in the year, or in certain parts of their geographic ranges. It is an open question whether the hand of man has, up to the present time, appreciably damaged the numerical stock of any of the fishes that support the great offshore fisheries (with the notable exception of the halibut, perhaps also of the Pacific albacore), but the fisheries bureaus are now much concerned with the danger that a fishery increasing in intensity may so reduce the average size of the individual fish taken that the total weight of fish caught per unit of effort will seriously decrease. It was the situation with regard to the plaice, with the fears felt for the future of other equally important fisheries in the North Sea, that led the nations bordering on the latter to organize the International Council for the Exploration of the Sea in 1902. And acute apprehension is now felt for the haddock in American waters, because its concentration on grounds where otter-trawlers can easily work makes it especially vulnerable to the rapidly expanding fishery.

It is obvious that if any species be fished down below the limit of safety, the remedy lies in such regulation of the fishery as will allow the stock to recover; whether by closed seasons, by closed areas, or by otherwise limiting the catch. But regulation of this sort must inevitably cause serious disturbance, loss, and hardship to the fishing industry. It is, therefore, of great importance from the economic standpoint to be able to state whether a shrinkage in the catch of one or other of the important species does actually mean that depletion is in progress at the hands of the fisherman.

In the past any sudden decrease in the yield of a fishery has usually been blamed, forthwith, to overfishing, or to the development of modern methods more effective than those of the past. In fact, whenever any improved method of fishing is introduced, a wail of calamity is at once heard. It is claimed that the young fish are destroyed, the sea bottom disturbed, and so forth and so forth, and investigation is demanded. Such an investigation, for instance, has recently been made of the effect of the otter-trawl fishery in Canadian waters, though this method has been employed for many years off northern Europe and the United States. But when, as often happens, the stock of some fish that had been at a low ebb over a period of years reestablishes itself in the face of a fishery, perhaps even increasing in intensity, it is clear that some factor other than overfishing is at work: the industry then requires protection more than the fish. It has, indeed, been amply proved that the stocks of many sea fishes (perhaps of all) may vary greatly in abundance from year to year, or over periods of years, from strictly natural causes, with which the hand of man has had nothing whatever to do.

Natural fluctuations of this sort have been so freely discussed in the literature of the fisheries during the past quarter-century that it will be enough to mention a few instances here. In general, they mirror the fact that a year of highly successful reproduction is a decidedly rare event for many species; and that when (by a happy combination of circumstances) such an event does occur, its product may dominate the stock for a long period thereafter, either until they drop out of the picture by the natural death-rate, or until another rich year class is produced. Thus the fish hatched in 1904 dominated the stock of sea herring in Norwegian waters from 1907 until 1919, having supported the fishery for twelve years. Had they not been succeeded by another abundant year class before they died (or were killed), the Norwegian herring fishery would have failed utterly for the time being; and no human endeavor could have staved off the calamity. Off the Newfoundland coast of the Gulf of St. Lawrence the crop of 1904 was likewise responsible for most of the commercial catch of herring as late as 1915. A still more striking example of fluctuations in abundance is afforded by the mackerel in American waters, causing vicissitudes to the fishing industry that have become proverbial: the recovery of the stock of mackerel from its lowest point, in 1910, to its present strength, took place in the face of very intensive fishing.

The fall and rise of the bluefish (*Pomatomus saltatrix*) off southern New England in the late 1700's and early 1800's equally affords a demonstrative illustration of the fact that events of this sort may be wholly independent of man, for decline, total disappearance, and subsequent recovery of this species took place before any considerable fishery for it had developed. In Norway, the historic record discloses a succession of declines and recoveries in the stock of cod over a long period of years. In Scotland the haddock failed in 1792, but recovered thereafter; the French (true) sardine has also undergone wide fluctuations in abundance, while many other instances of this sort might be mentioned, reaching back as far as the history of the fisheries runs, the economic sequellæ of which have been far-reaching, alternately bringing prosperity and disaster to the fishermen.

The stock of a given species may also be suddenly reduced almost to the vanishing point by some unfavorable shift in the environment; most often by abnormally low temperatures. We have record of such an event as far back as 1789, when seafarers brought back word that the surface of Barents Sea, north of Europe, was covered with large haddock and coalfish in dying condition; probably they had been chilled by some sporadic flooding of the bottom by Arctic water. A more recent and much heralded instance of destruction of this same sort was that of the tilefish (Lopholatilus) off the eastern United States, in the spring of 1882, when vessel after vessel reported these fish dead and dying on the surface. In fact, the destruction was so nearly complete that it was not until ten years later that a single live tilefish was again seen. But by 1898 they were again as plentiful as ever.

With the stock of any species of fish in the sea likely at any time to diminish, and to stay at a low ebb for years, from natural causes, as well as standing in danger of reduction by man, it is economically of great importance to be able to state in any given instance whether a shrinkage in the catch falls in the one category or in the other, because the procedure proper for the industry to follow may be quite different in the one case than in the other. If depletion be taking place, regulation, as already remarked, is in order; for it is certain that we cannot maintain any of the true marine fishes by artificial propagation if they be overfished. Boast as we may of the billions of young cod, haddock, or others that are dumped into the sea by the government hatcheries, these are less than a drop in the bucket: the product of only a handful of parents in populations to be numbered by the million. But if fish diminish as some one dominant year class dies off, before another year of abundant production has come, it is the fishery that needs to be safeguarded against the disastrous results of a sudden cessation of the supply.

Theoretically, extensive protective regulation might seem called for in this case also. Practically, however, this has not proved to be the case, because we know of no instance, up to the present, where the stock of a species that has shrunk from natural causes has failed to recover from such a decline in spite of the drain upon it by the fishery. When fish are scarce, there is less fishing done, so that this side of the picture takes care of itself. And the oceanographer stands in the best position to guard the fishery (and the consuming public) against fluctuations of this sort, for he alone has the opportunity to discover a rational basis for predicting such events in advance.

The basic fisheries problem, then, is to make the greatest possible use of the food resources of the sea that is compatible with avoiding the danger of overfishing; and at the same time to help the industry order its undertakings so that it will not suffer from unpreventable fluctuations in the available supply of fish.

Although the problems involved in these two cases are fundamentally distinct, in either case the solution can only come from investigations of the life histories of the fishes involved, and of their reactions to their environment, animate and inanimate, combined with statistical study of the commercial catch. In other words, the technique of oceanic biology must be invoked, whether the aim be protection or prediction. Whenever any fishery increases greatly in intensity, as happened in the North Sea after the war, and as is now happening with the American haddock, the immediate practical task is in general to estimate the strain of fishing that the species in question may reasonably be expected to withstand:—to determine, in particular, the upper size limit of the individual fish, to which the stock may most profitably, but at the same time safely, be fished down, involving determination of what is termed the replacement — surplus as an index to the safe yield. When any fishery shows a serious decline, the first question is whether this decline reflects overfishing, or whether it results from a natural decrease in the stock in the sea. In either case the species concerned must be studied as populations, not as individuals; methods similar to those developed in the science of vital statistics must therefore be invoked.

The potential usefulness of this line of attack is so widely recognized that the governments of northern Europe, Canada, and the United States have expended large sums for the collection and analysis of catch records and of market measurements. Although the masses of raw data assembled have assumed formidable proportions and although an efficient technique of analysis has been developed, the results, whether in abstract knowledge or in practical returns, have not been commensurate with the expenditures of money and effort. Thus, to quote the most notorious example, there is no general agreement as to the meaning of the fluctuations that have taken place in the plaice fishery of the North Sea region as a whole, nor in the relative abundance of small and large plaice in the commercial catch, one school explaining the recorded phenomena in one way, another in another, although this fish has been under statistical examination by many hands for many years.

In fact, it is not too much to say that if we regard the time and effort that have been expended in investigations of the sea fisheries as capital, this has as yet returned but a low rate of interest to the fishing industry, or through them, to the consumers ashore.

The basic cause of poverty of result from so great an effort has been the difficulty, when attacking problems of such magnitude and such complexity, of obtaining data adequate to attainment of the ends sought.

The chief deficiencies have been of two sorts: (1) Qualitative defects in the data that have been assembled as to the commercial catches. (2) Inability to carry out the necessary investigations into the basic biology of the commercial species.

Although records of the catch of commercial fishes have been compiled for many years in many countries, in many cases computations based upon them have been of little value, because the primary data have not classified the origin of the catches in sufficient detail, and because they have not included information as to the methods of capture precise enough to permit analysis in terms of return per unit of fishing effort. As the importance of this last measure seems not to be sufficiently appreciated (outside the fisheries services), it is worth remark, in passing, that a decrease in the total catch of any fish, meaning one thing if accompanying a decrease in the intensity of fishing, might mean something entirely different if it were the accompaniment of an increase in intensity. There are also other obvious reasons why statistics of the amount of fish caught may give an erroneous picture of the abundance of the species in the sea. When purse seiners, for example, take few mackerel, it may simply mean that the fish are too deep in the water to be caught by this particular gear. Or when otter-trawlers report 'few cod,' the latter may simply have congregated on the rougher bottom where the trawlers do not fish; or may otherwise have shifted ground.

The burden of furnishing information sufficient for the compilation of an adequate statistical record weighs heavily upon the industry; it is difficult to persuade individuals and organizations concerned primarily with immediate and pressing business interests to assume this burden, benefits of which appear to them doubtful or at least extremely remote. Nor has it been possible as yet to arouse a public demand that persons engaged in exploiting natural resources be required as a matter of principle to account in detail for the public property taken. Nevertheless, while the obstacles in the way of obtaining satisfactory fisheries statistics have at times seemed almost insurmountable, improvement is constantly being made. And with progress on this side, the need of similar advances in our knowledge of the life histories of the fishes concerned becomes the more pressing because more and more likely to yield practical benefits.

Here, too, much effort has been expended, and a mass of raw data bearing on various phases has been accumulated and published. But interpretation has lagged, due to our general ignorance of the interrelationships in the very complex chain of events in the sea that govern the comparative success or failure of its inhabitants in the struggle for life. Nothing in the sea falls haphazard: if we cannot predict, it is because we do not know the cause, or how the cause works. The obstacle to the advance of knowledge here lies in part in the technical difficulty of carrying on the needed investigations into the basic biology of the commercial fishes on a scale comprehensive enough to serve as foundation for investigation into particular phases. A more serious obstacle when seeking support (intellectual or financial) for such work is that in every case the matter is so obscure that it is impossible to predict in advance what particular phase in the fishes' life history will prove to be the vital one, or even that knowledge of any one is more important than of any other. That is to say, the whole life chain must be traced link by link before any sound understanding of it can be reached, which calls for critical and protracted investigations in biology (including physiology), often ramifying into chemistry and physics. Consequently, if the conservation and development of the marine fisheries is to rest on a sound basis, many problems must be attacked in the sea that seem at first sight utterly remote from any practical application. But only recently has it been possible in fisheries investigations to secure the necessary financial support for such work over a period long enough for the study to reach a productive state, and when such problems have been attacked by governmental establishments, the accumulation of raw data has in many cases far outstripped the digestion which is its sole object.

This one-sided development has its reflection in the fact that we do not yet know what precise combination of factors favors or opposes a good year of production for a single species of marine fish.

The question at what age it is wisest to catch and market the crop of any species, i.e., whether the best yields will result in the long run if the fish are taken near the lower limit of marketable size, or whether they should be allowed to grow larger and to spawn several times, is one of immediate importance in the case of several of the great fisheries, and will become so in the case of others.

Obviously, if a species is to persist, some individuals must grow to breeding age. But as only a fraction of each year's crop can do so in any event (else the universe would be a solid mass of fish) it may be wise for the fishermen to utilize the smaller sizes, most of which could not mature. For instance, we are totally in the dark as to whether the great destruction of immature fish, too small for the market, that is wrought by the otter-trawlers in the two sides of the North Atlantic, and by the pound nets along the Atlantic coast of the United States, so often heralded by calamity-criers, does any real damage to the stock; it may conceivably be a benefit, paradoxical though this may seem. To be more specific, there is no positive evidence that the annual capture of a billion or more of small herring in the Gulf of Maine, to be packed as 'sardines,' year after year, has had any effect whatever on the numerical strength of the stock of adults breeding there. Could a large catch of the latter have been made with equal impunity? We cannot answer. Similarly, it is now a moot question in what localities it is wiser to protect the small lobsters, but market the large, and *vice versa*; nor can this be settled correctly by argument, any more than can the questions whether large catches of small plaice in the North Sea are really as destructive to the stock as has often been supposed, or whether the size limit to which haddock are now fished down there would prove the wisest in the long run if present methods are continued.

For few species can we intelligently answer the question, Where ought the fish to be caught? — though this may be an important one in the maintenance or development of any given fishery. Practical fishermen have long feared the results of hard fishing on the spawning grounds, especially in the case of the flat fishes, though economic pressure has forced them to do just this, for it is often on the spawning grounds that drift-netting and otter-trawling are the most productive. On the other hand, we already know that there are certain grounds where no amount of fishing for certain species (even to the verge of temporary extermination) will have any permanent effect upon the general stock. This applies in cases where there is a regular emigration away from the spawning areas to grounds far distant, with no return migration. Thus the lobsters that stray to the Bay of Fundy cannot reproduce in the low temperatures prevailing there, though they find these cool conditions favorable to mature growth. It would be pure economic waste not to catch them; but is wisest to allow them to grow to large size before doing so. The case is apparently similar for the stock of rosefish (Sebastes) off the west coast of Greenland, which are largely recruited from fry produced in high temperatures in the Atlantic to the south. In such cases the only sound limit to fishing is the economic one. But the understanding of instances of this sort involves a knowledge of the lines of dispersal and migrations in general, which in turn may demand long-continuing study (by all available methods) of ocean currents as carriers of eggs and larvæ; and of the length of time during which these latter drift at the mercy of the current; information which, again, can only be gained at sea.

Another factor in determining where (from the standpoint of conversation) it is wisest to fish is the extent to which grounds where cod, haddock, and so forth, are little fished at present serve as reservoirs of supply for banks fished more intensively because more accessible; what protection, if any, should they receive on this score? That banks do serve as reservoirs for one another in this respect is certain, because when small grounds close to land are so fished out that it no longer pays to visit them (as happens often, and sometimes very soon) they presently recover if the fishermen abandon them for a term of years. In fact, a power of rapid recuperation seems almost an invariable law in the sea; any species, indeed, that did not possess this power would soon vanish from the scene, fishing or no fishing, by so many dangers and so constant are they all beset. What rôle in this recuperation is played by immigration from surrounding grounds, what by local reproduction? In the case of the Pacific halibut this is a live question today, and the answer to it will govern the regulations to be adopted. Its solution can only be reached through a study of migration, and of the factors determining the success of breeding, so that the International Fisheries Commission is governing its procedure accordingly.

At first sight it might seem that the question 'how' best to harvest the crop would be purely economic, not biologic. Actually, however, this is not the case, for many reasons. Thus different kinds of gear take fish of different sizes, while the type of gear used may also determine the fishing grounds frequented, and the depth zone available for fishing. The otter-trawl, for instance, can be used only on comparatively smooth bottom, the purse seine only close to the surface, and in smooth weather; the pound net or weir only close to the shoreline, and only during the warm months if ice forms during the winter; hook and line only where fish are feeding, and so forth. Whether the grounds, depths, or seasons, so determined by the method adopted, are wise from the standpoint of conservation, or the reverse, can be settled only by knowledge of the life history of the particular fish.

'How to fish' has another biological aspect that cannot be neglected: namely the effect that the fishery may have on enemy-species that are caught incidentally, or on species upon which the commercial fishes prey. Any method that will take and destroy large numbers of destructive species may actually benefit the primary object of the fishery, in spite of the draft that fishing makes on the latter. In North American waters this applies especially to the destruction of dogfish, of skates, and of the goose — or monkfish (Lophius). But off other coasts, where the last two are used for food, the relationship is different. To destroy annually several hundred million menhaden (Brevoortia), as is done to supply the demand for fish oil and for fertilizer, may seriously lessen the food supply for the bluefish (Pomatomus), and so react against the latter. But the lives of so many menhaden are saved whenever a bluefish is caught that its death may be economic gain. The interrelationship of different species, as food or enemies, is thus a vital factor in the situation; to disentangle this skein falls directly within the province of the oceanic biologist.

Ever since man first cast line into the sea, Can we broaden our fishing grounds? has been a live question. With the passage of the years one new fishing bank has been developed after another, and no one can dispute that the discovery of new grounds and of new bodies of fish from which no toll has previously been taken, is so much pure gain. Practical fishermen and fisheries bureaus are therefore interested in testing the possibilities of unfinished parts of the sea by actual fishing experiments, such, for instance, as have been carried on during recent years in South African waters. Although it is certain that the major fishing grounds off the North Atlantic coasts of Europe and of North America are already being exploited extensively — so, too, off the North Pacific coast of North America — some extension may be expected even there; witness the development of a productive fishery in water deeper than the local trawlers had previously frequented for hake (Merluccius) as recently as about 1903. And much greater possibilities of expansion still remain in the Gulf of Mexico, in the South Atlantic, in the eastern and western Pacific, and in the Indian Ocean, as well as in Arctic and Antarctic Seas. Less direct methods have also proved fertile from this standpoint. For example, highly productive cod grounds have been developed off Norway by deducing the existence of spawning schools from the distribution of their eggs floating at the surface of the water.

The question of extension of grounds is, however, not a simple one of exploration, because expansion might in certain cases prove detrimental to some of the most important species. For example, it is questionable whether the stocks of sea bass (Centropistes) of scup (Stenotomus) and of various other fishes that vanish from the eastern coast of the United States in winter can stand the added strain of the year-round fishery that is developing now that their wintering ground has been found.

The possibility of discovering new fishes, or of mapping the centers of abundance for species whose existence has long been known but which have not been made the object of any regular fishery, because their abundance is not suspected, is closely associated with the development of new grounds. One might hardly have expected that the existence of a large and valuable food fish, in great abundance, and close to the fishing ports of the eastern United States, would have remained unknown until 1879. Such, however, was the history of the tilefish. The first specimen of this species was brought in by a fisherman, but it needed the explorations of the United States Bureau of Fisheries to make its geographic distribution and abundance known and to introduce it to the market. Thanks to these efforts, the tilefish has of late yielded much good food. And while history can hardly be expected to repeat itself in so spectacular a way in the North Atlantic, unlimited possibilities for this sort of expansion are still open in the other oceans. In fact, the sea is certainly capable of yielding vastly more food to man than at present. There are also attractive possibilities of expanding the yield of fish products other than food, especially fertilizer, stock food, oil, glue, and so forth, and fish skins as a source for leather. In fact the catch of one species alone (the menhaden) used exclusively for fertilizer, scrap, and oil along the Atlantic coast of the United States, is about 700,000,000 pounds yearly.

In the case of the shell fisheries (for clams, oysters, mussels, abalones, pearl-oysters, lobsters, crayfishes, crabs, shrimps, prawns, and so forth) the great problem is to guard against depletion by overfishing, or to replenish the stock by cultural methods. This danger is much more imminent for the mollusks and for certain of the crustacea (lobsters, crabs) than it is for most of the marine fishes, because these (including all the mollusks now used for food) live close to shore in shoal water; also, in the case of mollusks, because they are so stationary that once a center of abundance is found, it is soon fished with great intensity. The result is that the maintenance of the stocks of oysters, clams, abalones, and so forth, around our coasts is already an urgent matter, and it has been found necessary severely to regulate the pearl fishery wherever this is carried on in the Indo-Pacific. To emphasize the economic importance of the shellfish (mollusks, lobsters, crabs, and shrimps) we may point out that they form about one fifth [1] of the total sea foods harvested from the Atlantic coast of the United States, while oyster shells also yield about 6000 tons of lime there, as a by-product, yearly.

The stationary nature, however, of these mollusks, and the possibility of cultivating them, as is now successfully done with clams and oysters, makes it easier to safeguard them than the fishes. But detailed knowledge of their lives and ecological relationships is an absolute essential, not only for cultivation, but equally for regulating the catch from grounds, or of species not susceptible to cultural methods. And this knowledge can come only from detailed studies falling in the field of marine physiology.

In short, every problem of the marine fisheries, except such as center directly around the education of the human palate to appreciate new foods and of human industries to employ raw products from new sources, or around improved methods of distribution, handling, and marketing, is a problem in oce-

[1] Oysters and clams figured without their shells.

anic biology by whatever technique it be attacked, just as every problem in plant or animal husbandry on land is one in terrestrial biology: consequently, a problem falling directly within the direct scope of oceanography. Every such problem demands for its solution precisely the procedure that would be employed had it no economic bearing whatsoever; results gained in any other way can never be better than haphazard; i.e., of the sort proper to a past age.

This means that whatever marine animal be in question, whatever be the immediate question regarding it, and whatever method, statistical, observational, or experimental be employed for the solution of the latter, an understanding of the whole life cycle of the species must finally be arrived at for a complete answer: fisheries biologists have long appreciated this truth. And a growing demand for information on such points as spawning grounds, rate of growth, feeding habits, and migration, is evidence that the fishery industry is also coming to realize it.

It is no reflection on science that only certain of the links in the life chain are yet known for any fish in the sea, because every case is one of great complexity, involving, *inter alia*, the physiological state of the parent as determining the viability of the eggs and sperm; the temperature and salinity of the water as governing the hatch; the character of the eggs, whether buoyant or not; the duration of incubation, and the drift of the water as governing their dispersal; as well as the supply of food — unicellular plants or minute animals — available when the little fishes hatch: this last is probably the most vulnerable stage. The toll taken of the larvæ by enemies is also important. Probably these headings include the factors that chiefly govern the relative success of reproduction from year to year; hence to understand the natural fluctuations of the stock, knowledge of these factors is as essential as is knowledge of the inroads made by man for understanding the effect that the fishery has upon the crop of adults. But it is about precisely these matters that we still remain in the deepest darkness. Such investigations in their ramification also involve the life histories of various species of plants and of animals that may either serve the fish in question as food in one stage or another of its development, that may serve as the food of its food, or that may prey upon it. Whatever reacts favorably or unfavorably on the one, will react likewise on all the rest.

It is no wonder, then, that fisheries biologists have harped on the practical importance to fishermen, and so, in turn, to the purse of the consumer, of the welfare of the minute creatures in the sea on which young fishes feed, finally harking back (*via* their own food) to such elemental matters as the salts in the sea, and the amount of sunlight falling on the surface of the water.

The direction and duration of the involuntary or passive migrations of the larvæ, their food, their rate of growth, and the age at which they either take to the bottom or begin to direct their own journeys, is one factor; wanderings of the older fish, the other, that governs the interchange of fish between different banks, and the degree to which certain grounds serve as nurseries for others. This, with the importance of temperature as a vital factor, makes the study of the ocean currents one of the most important items in fisheries research today. Knowledge of such matters as the food and spawning habits of the adults, of their rate of growth, of the dominance of particular year classes, of the enemies, of the general distribution, and of the optimum temperature and salinity for the older fish are equally essential for intelligent management of the fishery.

There is nothing fanciful or extreme in the foregoing: to cover the whole field must be the ultimate aim if measures of conversation are not only to be effective, but at the same time are to impose the minimum of hardship upon the fisherman. This, in principle, is now accepted by all who concern themselves with the preservation of the deep-sea fisheries, as illustrated by the program of the International Fisheries Commission, charged by treaty between the United States and Canada with the proper regulation of the halibut fishery off the northwest coast of North America. Rapid depletion makes regulation necessary in this case, as already remarked (page 195). In fact, as the United States Commissioner of Fisheries has pointed out, the fishery is in a very serious condition from overfishing. But to arrive at a basis for action, the Commission has found it necessary to search for the eggs and larvæ, to map the drift of the same, to examine the dynamic oceanography of the region as governing this drift, to trace the wanderings of the adult halibut, to chart the spawning grounds, and to trace the interrelationships between the stocks of halibut on different grounds.

When seeking a basis from which to predict the productivity of a fishery, for a given season or period of years, an essentially similar method of procedure is requisite. The United States Bureau of Fisheries has, for example, undertaken an intensive study of much these same phases in the life history of the American mackerel, hoping to be able to warn the industry, in advance, of the violent and uncontrollable fluctuations in the number of mackerel existing in the sea that come from natural causes. And though this study has been in progress for only four years, predictions of the mackerel fishery for 1928 and 1929, based on the state of the stock in 1927 and 1928, were close to correct. Predictions of the abundance or reverse of herring and of sardines in European waters, based on similar studies, have also been successful enough to justify the hope that they will be of great and increasing value as a better knowledge of the governing causes is gained.

It is idle to suppose that oceanwide expeditions, undertaken at long intervals, will be of much value in advancing investigations of this sort. What is needed is intensive study either of regions, of individual species, or of particular fisheries, as the case may be. These must be so long continued (because covering so wide a field and concerned with the natural economy of generation after generation), and so intensive (because of the nature of the problems involved), that individual investigators can make but slow progress. In no field, in fact, are joint efforts and the services of coöperative agencies more needed in oceanography, than in fisheries biology; and in none is it more necessary to give attention to problems that may at first seem remote from any direct economic bearing.

2. Navigational Problems

In a general way, the sea now serves man's purposes adequately as a high road for commerce. But now and then, even in this era of full-powered steamers and elaborate safety devices, we have brought home to us in a tragic way that the sea still has its dangers: we may be shocked to hear of a collision with ice, as chanced to the 'Titanic' in 1912; of the foundering of a steamer, its plates stove in by the force of the sea; or of the stranding of some ship put out of her reckoning by an unexpected current. The high rates of marine insurance, as compared with insurance on goods in transit on land, mirror the risk to property run on every passage.

Probably the greatest gain that oceanography could offer in cheapening, expediting, and safeguarding commerce on the seas, and the only considerable gain to be hoped from it in this respect at present, would come from adding detail to our knowledge of ocean drifts and of tidal currents, and of the depths of water off coasts not yet accurately chartered.

The importance of ocean currents in ordinary day-to-day navigation is so obvious as to need no emphasis here. Ignorance of the direction and velocity of the current is responsible for some of the discrepancies between the true position of the ship as determined by astronomical sights and that calculated for her by dead reckoning, though log errors, bad steering, leeway, and so forth, all enter in. A recent example of the tragic effects an unrecognized drift may have is afforded by the difficulty that ships coming to the assistance of the ill-fated 'Vestris' had in finding her; the fact that she was more than thirty miles from the calculated position, in a run of only two days, being perhaps best explained in this way. And many wrecks have been caused by ignorance of the direction and strength of the current near shore at the time.

It is self-evident that to follow a favoring current hastens, to stem a contrary current retards, passages. This is made particularly true off the east coast of the United States by the proximity of the so-called 'Gulf Stream,' the drift of which must always be taken into account. Every hour wasted steaming against the current entails so much extra cost; wherever it is possible to go with the drift, fuel is saved. And either small savings, or small losses, when cumulative, reach staggering proportions in the course of years. This factor is of far greater moment for the slow freighters, in which most of the world's maritime commerce is carried, than for the fast passenger liners which can often disregard the current. In parts of the South Atlantic, Indian, and Pacific Oceans we still lack sufficiently detailed knowledge of velocities and precise directions of the currents, of the effects on these of varying winds, and of seasonal variations to allow intelligent planning of routes for slow ships, even though the general characteristics of the oceanic circulation are understood.

The aggregate economic loss from such ignorance, if measured in dollars and cents, would be very large. Even when the current arrows are true enough as an indication of the mean direction, the actual drift at any given date may differ widely from that shown, and this is what the navigator wants to know.

This need of bettering our present knowledge of the major currents is fully appreciated by the hydrographic services of the seafaring nations. For this reason the British Admiralty, the United States Hydrographic Office, and the German Marine Observatory, among others, are continually accumulating a vast amount of data from vessels' log books, as well as from all other available sources, in the hope of improving their yearly and monthly current charts. Such information is, of course, most important for the regions where the direction of the dominant drift reverses from season to season, as in parts of the Indian Ocean; or which fall within the sweep of a great current at one season, but not at another; or over which the daily velocity varies greatly from season to season with varying winds.

In certain regions, as along the west coast of Africa, and in the Red Sea, rapid advances in knowledge of the currents have been gained within the last few years. But to illustrate the urgent need of still further improvements even in more traveled seas, we need only instance the present vagueness of our understanding of the secular variations in the geographic location of the inner edge of the Gulf Stream drift off the east coast of North America, and of the eddying movements plus counter drifts that confuse the orderly procession of that body of tropic water toward the northeast. That the Gulf Stream has shifted its position is a frequent report; one, too, that includes more than a grain of truth. Knowledge of the southerly drift along the west coast of North America is still vague. More detailed information is made especially urgent there for the sake of safety at sea by the scarcity of good harbors of refuge along the coasts of Oregon and California. And 'sketchy' fairly describes our present picture of the currents among the Polynesian, Philippine, and Malayan Archipelagoes, to mention only a few striking instances.

Ocean currents affect navigation indirectly as well as directly, and in a disastrous way, by bringing icebergs and field ice down from the Arctic, a frequent menace to the shipping lanes between America and Europe. This danger the maritime nations now meet in part by maintaining the International Ice Patrol, during the danger season, in the region of the Grand Banks of Newfoundland, where the steamer routes between the United States and northern Europe touch the principal lane followed by the bergs in their drift southward from Davis Strait. Betterment of this patrol demands more detailed examination of the variations in the two great currents (Labrador and Gulf Stream) that meet here, the first bringing the bergs, the latter melting them, for it has been appreciated, from the beginning, that the task of following the drifts of individual bergs would be greatly facilitated by knowledge of the circulation of water in the region as existing at the time. The dynamic and other hydrologic studies that the patrol cutters carry out, with this end in view, are therefore of direct economic value. To gain a sounder understanding of the factors that control the journeyings of the ice, the service has recently expanded its activities to include a dynamic survey of the whole region between Labrador and Greenland, as described in another section (page 103). And should the patrol be extended to include the more northern routes, it will become increasingly important to make periodic surveys of these northern waters in the hope of explaining (perhaps predicting) the wide variations in the amount of ice that comes southward from year to year, and the varying tracks that the bergs follow.

As demands grow for an extension of maritime trade routes more and more to the north, the need of detailed information as to the state of the Arctic ice from season to season correspondingly increases.

Thus it is a live question how many months in the year open water can be depended upon in Hudson Strait and in the northern and northeastern parts of Hudson Bay, for the answer will determine the practicability of developing the harbors on the Bay as export centers for wheat, and so forth, from the Canadian Northwest, in competition with the harbors in the Gulf of St. Lawrence and to the southward. In this case the drift of ice from the north will govern, not the ice frozen locally in these comparatively low latitudes; a drift, in turn determined by the dominant movement of the water in its course out of the Bay and through Hudson Strait. The Canadian Government is fully alive to the importance of this matter, and has already sent several expeditions to the Strait.

The rapid development of air navigation, leading to attempts to develop safe flying routes over the top of the world (to shorten the distance between America and northern Europe), gives added significance to the state of the ice in the Arctic, especially to the northward of Spitzbergen, from season to season, and from year to year.

For these navigational reasons, as well as in the interests of the fisheries (page 219) and for the general advancement of science, we need not only a better knowledge of the circulatory events in the sea, but better understanding of the basic forces that keep the ocean currents in motion, as well as of the relative effects of the conflicting factors that influence their set and drift. This cannot be gained by continued compilation of log-reports, no matter how extensive, because the underlying waters are involved, as well as the surface. Quite other procedures are called for, as described above (page 98). Work of this sort, however, can seldom be attempted on a large scale by any governmental establishment, because the difficulty of demonstrating an immediate economic result makes legislative support difficult to win. And while the development of methods of attack, and so forth, often draws inspiration from one or another isolated center or individual, successful application to the oceans demands coöperation between many institutions, because the field is ocean-wide. Observations must also be carried on for many years to trace the long-time fluctuations that are already known to occur.

In many parts of the world the tidal currents run with velocities much greater than those of the ocean drifts on the high seas, and they are usually strongest next to the land, just where ships meet their greatest danger.[1] In fact they may play their greatest economic rôle within busy harbors.

[1] Contrary to the belief among landsmen, the well-found ship is safest when far out at sea: when skirting the land, she is in constant risk.

It is easier to study tidal currents than ocean drifts because most of the work can be done near land, in shallow, and often within enclosed waters. Under such conditions the direction and speed can be measured directly from hour to hour as the tide ebbs and flows by current meters, by chip-log, or by float. And an enormous amount of this work has been done by the tidal services of the different countries, including continuous observations over periods of many weeks or months at strategic locations (lightships, for instance). But while the stage of the tide can now be predicted in advance for any time of the day with great accuracy for most of the important harbors of the world, knowledge is far less advanced concerning the velocity and set of the tidal currents. Current surveys with this end in view are now being carried on along the coasts and in the more important harbors of the chief maritime nations by their respective surveys, but progress, necessarily, is slow with the appropriations available. And for administrative reasons the coastal and tidal surveys of the different governments are seldom able (never able in the case of the United States) to extend this work beyond their own coasts or those of their dependencies. Even in frequented waterways, other than harbors, present information is, in most cases, insufficient — witness the necessity the engineers for the projected tidal-power development in

Passamaquoddy Bay have been under of making their own survey of the strengths and directions of the tidal currents there. Knowledge of the latter is even more elementary around the shorelines and in the bays and estuaries of all the countries that are more backward in this respect, for what is known of such regions has necessarily been gathered more or less haphazard, as opportunities offered for some man-of-war or other ship to take current measurements while on foreign station. The paucity of detail as to the direction and velocity of the tidal currents given in the sailing pilots for South Atlantic coasts, for the island groups of the Central Pacific, and for the Eastern Archipelago will make this clear. And nowhere, in the open ocean, is it yet possible to predict the pure tidal current, because the latter is so often complicated by the wind, and by whatever non-tidal drift may dominate the region in question.

Here a wide field lies open for oceanographic research, where knowledge gained will sooner or later be of practical advantage to the navigator.

Knowledge of the topography of the sea bottom — i.e., of the depth of the water — along the coast is, to the navigator, as important as is the detailed charting of the coastline itself. Not only does his ability to enter harbors in safety depend on this knowledge, but by sounding he can feel his way, and often can locate his position, when fog or storm hides every visible mark, terrestrial or celestial.

Until very recently it has chiefly been in comparatively shoal water, say less than one hundred fathoms, that soundings have been helpful to the navigator, and the importance of mapping the depth near land in the greatest possible detail has so long been fully appreciated, and so much effort has been devoted to this, that existing charts leave little to be desired for navigational purposes, for the more frequented coasts.

An example of the accuracy of some of the older shoal water work is afforded by the fact that charts of the Maldive Group in the Indian Ocean, based on soundings taken nearly a century ago, are so accurate that no appreciable errors were found in 1901–02 except such as would naturally result from subsequent growth or death of coral heads. Even off the coasts as well known as those of the northeastern United States, however, pinnacle rocks have recently been discovered, and surveys must be repeated at frequent intervals off sandy coasts and inlets where bars shift and channels change. In fact, few laymen appreciate the extent of the coasts where knowledge of the depth is still more or less imperfect, or in need of frequent revision. For an example we need seek no further than the east coast of Labrador, where soundings are not only so few, but so many of them inaccurate, that a stranger must proceed with the greatest caution, while considerable stretches of that coastline itself are still to be filled in on the chart. In Alaskan waters employment of the 'wire drag' method has recently added much important information, especially as to the location of pinnacle rocks, such as are apt to be overlooked in other kinds of surveys.

Now that sonic methods of sounding have reached the stage of practicability, the application of measurement of depths to navigation enters a new phase. In the first place it is now possible to survey a given area much more rapidly than by the old methods. In the second, detailed information of the edges and slopes of the continents becomes increasingly important, for as more and more of the larger ships install sonic gear with which they can sound at any depth while running at full speed, they find it more and more helpful to pick up the slope as an index to their distance from land, in thick weather. Thus the International Ice Patrol, during the season of 1928, found the sonic fathometer of great assistance in navigating in the fog around the slopes of the Grand Banks of Newfoundland; had these slopes been better chartered the cutters could have placed much more dependence on the positions indicated by their own soundings.

3. Currents as Affecting Harbor Construction and the Protection of Shore Property

We can only reiterate what was pointed out at the Conference on Oceanography at the United States Navy Department in 1924, by General Edgar Jadwin, that the direction of the current must always be taken into account in planning harbor entrances on sandy coasts in order that the entrance jetties may be designed and constructed either to catch and hold the drifting sand, or to divert the latter past the entrance so as to prevent the filling of the channel with sand. The currents of importance in this case are those close along the tide-line; and at the times when these are strong enough to drift the sand along the shore, they may either be parallel to or opposite to the general dominant drift offshore, depending on the direction from which the storm waves travel, and the angle at which these strike the coastline. At the tip of Cape Cod, for example, the only storms that drive heavy enough seas against the beach to move much sand are from the eastern quadrant. Consequently, the beach drifting is toward the west and southwest, whereas the dominant movement of the water only a short distance offshore is in the opposite direction.

In any given case, therefore, a more detailed knowledge of beach drifting is requisite than has yet been gained for any considerable sector of the North

American coastline. An attempt made to reopen New Inlet, Dare County, North Carolina, affords an excellent example of what is apt to happen when harbor work is undertaken in ignorance of the beach currents. This inlet, which had closed shortly previous, was dredged open by the State of North Carolina at a large expense. But because of ignorance of the movements of the water along the beach, the channel was not protected against the drift of sand. The result was that before three months had passed the cut had entirely closed again, all the money that had been spent on the work was wasted, and the benefits that reopening of this inlet would have brought to the local fishery were lost. A small sum spent on studying the beach drift there, during storms, would have safeguarded work worth many thousands to the State.

All this applies equally to construction undertaken to protect shore property, much of which has defeated its own purpose, by setting in motion unexpected currents that have cut into the very stretches of beach they were planned to protect.

4. Soundings in Connection with the Laying of Submarine Cables

An accurate knowledge of the contour of the bottom of the ocean is essential for the laying of submarine cables. The more detailed the knowledge of the general region, the better can routes be planned to avoid the ridges and depressions of the sea floor, and the more precise the knowledge of a particular route, the less the surplus length, or slack that must be allowed to guard against unknown irregularities of the bottom. Such matters are being investigated along most of the existing cable routes, by commercial cable ships that carry on the work of repair and renewal, which are equipped with the best sounding gear yet developed.

As the commercial demand increases, new cables must be laid along new routes, across parts of the sea which, to date, have been but sketchily surveyed. It has been stated, for instance, that an adequate survey of the Japan Deep and of neighboring regions would be especially valuable from this standpoint, because lying in the route which will probably be chosen when additional cables are laid across the North Pacific, while projects to connect up the American with the British trans-Pacific cables will entail surveys between the Hawaiian and Fanning Islands. A survey is also needed direct from the Panama Canal to Honolulu; also additional information all along the Pacific coasts of South Central America, and South America, including those of outlying islands (the Galapagos, for instance), that might sometime be chosen for relay stations. As soon as commercial development in the southern hemisphere demands the extension of the present cable systems across the South Atlantic, South Pacific, and Indian Oceans, information far more detailed and accurate than is now available will certainly be required as to the depths and shapes of the bottom. The recent expedition of the 'Meteor' has given a preliminary picture of the bottom of the South Atlantic, but (from the cable standpoint) no more, and we believe we are correct in stating that until the 'Carnegie' undertook her last cruise, only one line of sonic soundings had been run across the South Pacific, this being the only method yet discovered by which detailed surveys of large areas of deep ocean can be made economically. The 'Carnegie,' before her destruction, and the 'Dana,' have added several profiles in the North and South Pacific, but vast areas in that ocean still remain virgin so far as detailed knowledge of their submarine topography is concerned, as remarked in an earlier chapter (page 22), which applies equally to the Indian Ocean.

According to a statement by Colonel C. A. Seone, to the Oceanographic Conference at the United States Navy Department, 1924, it was usual until very recently — i.e., so long as soundings in deep water could be made only with wire — to allow ten per cent excess length, or slack, to provide against unforeseen irregularities of the sea bottom. And it is not likely that any cable had been laid over a long distance with less than eight per cent of slack, until methods of sounding by echo were developed. Taking advantage of this improvement through surveys made by the United States Navy, the United States Army was able to relay its Alaskan cable with considerably less slack than ever had been done before, at a corresponding saving in cost, thanks to the more intimate knowledge of the topography of the bottom so gained. We are informed, however, by an official of one of the largest cable companies, that a method of measuring the depth in deep water more exactly than can be done with the sonic devices now in common use would be of great assistance in locating the ends of cables when broken, as happened to eleven off Newfoundland during the earthquake which shook the seaboard of the northeastern United States and Canada in November, 1929.

5. Oceanography and Seasonal Weather Forecasts

The question whether or not a rational basis for forecasting any features of the weather, for any part of the world, can be found in the variations that take place in the temperature of the sea, has been much discussed of late, both by meteorologists and by oceanographers.

In introducing this matter we must point out that its present economic status falls in a category quite different from that of the phases of oceanography already discussed in this chapter. The economic bearing of the exploration of tidal currents, for example, of the charting of coastlines and harbor approaches, or of the sounding-out of shoals is not only direct but immediate; that of many specific problems in fisheries biology is equally direct, if less immediate; and the practical importance of the more general phases of oceanic biology is unquestioned, if more remote. But there is, as yet, no general agreement whether, or to what degree, forecasts of the weather, based on the temperature or on any other feature of the water, can ever be made reliable enough to prove of general service to man, unless it be in specially favorable regions.

The first economic problem, then, to be solved in the oceanographic investigation of the interaction between sea and air is whether this does indeed offer reasonable prospect of yielding direct practical benefits as some meteorologists now confidently maintain but which others as confidently dispute. This ground is at present so controversial that the oceanographer must tread warily.

Furthermore, a clear distinction must be drawn between the type of weather prediction that could be furthered by studies of the atmosphere itself over the oceans (this is not a part of oceanography), and the type for which some meteorologists believe a rational basis can be found in the variations of the thermal state of the water. The first corresponds mostly to the sort of daily weather charting and forecasting now carried out on shore. If enough stations could be arranged for, properly distributed over the oceans, it would be possible to forecast the tracks of storms, directions of winds, and state of the weather a day or two in advance over the sea just as is now done on land. Meteorologists — the shipping interests, too — have long realized the desirability of such forecasts. The reason that their development has lagged in the past has been the difficulty and prohibitive expense of organizing a sufficient number of recording stations, the necessity for taking all observations from ships which makes it impracticable to establish fixed stations, and the weakening of the chain that would result from a failure to obtain regular reports from the less frequented seas. An attempt to meet these difficulties is now being made by the several weather services, by the designation of certain ships as reporting stations according to a uniform plan. The data so collected may be expected to serve as the nucleus for statistical studies, embracing also the vast amount of data that is concurrently collected by the great maritime nations.

There is no reason to suppose that any study of the surface temperature of the sea, of the evaporation, or of the variations in the ocean currents, no matter how detailed, could ever assist the general daily forecast, whether for sea or for land, because whatever changes take place within the sea (either with the alternations of the seasons or following extra-terrestrial causes) are events inordinately slow as contrasted with the sudden fluctuations in the atmosphere. The goal that some students believe attainable here is quite a different one, namely, reliable prediction of the seasonal weather character over the adjacent lands to leeward: even over lands far distant.

Ordinary weather forecasting, such as is now carried on by most of the civilized governments, has become so much a matter of course, is usually so well verified and is so universally used as a guide, that there is a constant demand for longer range predictions of just the sort that the proponents of forecasts based on sea temperatures hope to see realized; namely, to tell us weeks or months in advance whether high or low temperatures, much or little rainfall will prevail. Even in regions where the weather fluctuates widely from day to day it would, in many cases, be of great economic value to know in advance the direction of abnormality to be anticipated in these respects, even if its amount could not be foreseen. Thus a departure of a degree or two, plus or minus, from the normal temperature in winter may govern whether most of the precipitation of a northern region comes as rain or as snow, correspondingly affecting the ease of transportation, and so forth. Advance information of this sort would be so helpful a guide to many industries (we need only instance the clothing trades, power and transportation companies, and certain branches of agriculture), that attempts in that direction are constantly being made. And proof that industry as a whole would actually welcome assistance of this kind is found in the fact that many concerns are willing to pay high for such forecasts, even while realizing that their dependability is yet to be proved.

Forecasts of this type have been given out from one source or another in various parts of the world. Some of them have had no physical basis, while the sponsors of those few that have would be the first to declare that the data for their calculations have been far from adequate. Even such of the long range forecasts as are based on tangible factors have in most cases been purely empiric: deduced, for example, from astronomical cycles (planetary or solar), from correlations, or on the assumption that a periodicity recorded in the past will recur in the future. In most cases, publication of these forecasts has been abandoned before long, discredited by too frequent failure, on the part of the weather to substantiate the prediction. And it would certainly be premature to claim that any one has yet worked out a dependable sequence from antecedent events, whether in sky, in sea, or on land, from which the weather to come can be forecast far enough in advance for any considerable part of the earth's surface, or reliably enough year after year to serve as a trustworthy guide for man's activities.

This, however, does not necessarily mean that such a sequence, or sequences, cannot be found: on the contrary, there have been some promising developments of late. Thus government forecasts of the summer monsoon rainfall of India, based on oscillations in atmospheric pressure at stations bordering the Indian Ocean, have been reasonably successful in the long run, and well verified in occasional years, though poorly in others.

It has also been suggested, repeatedly, that at least a partial basis for such a sequence could be found in the sporadic variations that are known to take place in the surface temperature in various parts of these a, combined with any corresponding expansions or contractions of the ocean currents, and with the rate of evaporation from the surface. This is now being tested by the various comparisons between the physical state of the sea water and the local weather that are being carried on at present, especially for the North Atlantic; in Canada; in California; and in Java. For example, marine temperatures are now being used in an attempt to determine whether the weather in Europe or in the South Atlantic part of the United States shows dependence on conditions in the Gulf Stream. Predictions of the weather of Southern California developed at the Scripps Institution from the temperature of the adjacent sea during the preceding months have been verified to an encouraging degree for the past twelve years, with winter rainfall on land greater than normal when the neighboring sea has been cooler than usual during the preceding August–October, and *vice versa*, while attempts to forecast the amounts of rainfall have been about seventy-five per cent verified. Long-range forecasts based on similar factors are also being issued commercially from at least one private source in the United States, though so far as we are aware no independent analysis of the degree of verification has yet been attempted in this case.

It is obvious that studies of this class, if looking toward weather prediction based on oceanic temperatures, presuppose the occurrence of longer or shorter term fluctuations of temperature in the sea, of a sort that cannot be described as regularly 'seasonal.' And as pointed out on page 60, this supposition is amply justified, such variations having been observed so frequently in every part of the sea where the temperature has been studied in detail that they must be accepted as characteristic. But before the claim that these events can be used as a basis for weather prediction can be upheld it is necessary to establish, not only that a regular correlation exists between the two classes of phenomena for the parts of the earth in question, but that the changes in the sea regularly antedate the changes in the atmosphere, and not the reverse; also whether the former are so great that their effects are not entirely masked by the complex atmospheric phenomena that immediately control the weather.

This quantitative aspect of the problem is especially pressing because meteorologists and oceanographers have mostly to do here with minor fluctuations in the thermal state of the sea, seldom with major alterations of a sort that would strikingly be reflected in the weather of some part of the world, such as the heavy rains over parts of the Peruvian desert early in 1925, or the droughty and other consequences of unusual outbursts of polar ice. Though it is certain that minor fluctuations do occur commonly, little is known about them except in the marginal seas in high latitudes (just where they may be expected to reach their widest range). And while a progressive movement of such temperature abnormalities as develop may be expected to take place along the tracks of the major ocean currents, precise information on this point is much needed.

In the northern hemisphere, for example, easterly movements of this sort have most frequently been traced in latitudes north of the fortieth parallel. But this may partly be because the temperature abnormalities so far actually recorded (not surmised) have been much greater in high latitudes than in low, allowing their progression to be followed more certainly. To illustrate the difficulty of tracing, across the oceans, the small thermal variations that have been recorded in the tropics, from the usual records supplied by passing ships, we may instance the Caribbean Sea where data tabulated by the United States Weather Bureau for the nine years 1920–29 showed a maximum monthly departure of 1.2° F. from the mean; with only 39 months of the 100 showing deviations greater than .5° F.

The crux of the matter is, however, to establish beyond reasonable doubt whether, or in what parts of the ocean, temperature abnormalities or other changes in the water do actually antedate alterations in the weather of the overlying air with regularity. Nor can any general rule be assumed to apply, *ipso facto*, in this respect, whether regionally or seasonally, the whole question being an extremely complex one. The sequence is not yet clear, even for regions where sea and air temperatures have been under observation for many years. In the Gulf of Maine, to note a single example, it is sufficiently demonstrated that the temperature of the air and direction of the wind largely control the temperature of the water in winter. However, the subsequent effects on New England weather of these weather-produced water temperatures are unknown. Off Southern California, again, the wind affects the temperature of the surface both by producing up-welling from below, and by sweeping cold water down from the North. How these temperatures re-act on the temperature of the air, and so on the weather, is now the subject of active investigation at the Scripps Institution. It has often been stated that for Scandinavia various atmospheric and terres-trial phenomena follow the cycle of sea temperature. But recent students have found the sequence to be the reverse, for, while a close correlation has been shown to exist between air and water temperatures along the coast of Norway, it now seems that the variations in air temperature precede those in the water more frequently than the reverse. Neverthe-less, this does not necessarily indicate that the at-mospheric changes are the primary ones in such cases, for the more mobile air may bring departures in temperature to a given coast more rapidly than the warmer or colder water can reach there, though this water may be their cause.

This uncertainty as to the true sequence applies not only to the conditions regularly prevailing over one part of the sea or another, but even to sporadic events that have often been invoked as evidence of the climatic effects of marine abnormalities; to the torrential rains, for instance, that accompanied the abnormal development of the warm 'El Nino' current along the coasts of Ecuador and of northern Peru early in 1925. Although most, if not all, students who have published accounts of this event have looked to the high temperature of the neighboring sea at the time as the cause of the exceptional rainfall that attended, it has been pointed out to us that no definite proof of this has yet been brought out. While the alteration of ocean currents in the regions was probably a contributing factor, both events may have been coincident results of a common cause — marked reduction in the strength of the trade winds.

Uncertainty of another sort as to which is cause, which effect, is illustrated in the North Atlantic, where recent and very searching investigations point to the direction of the wind as a cause of variations in the winter temperature of the surface of the sea, but where the winds in turn reflect the locations and intensities of the permanent or semipermanent centers of high and low atmospheric pressures, which may themselves be more or less affected by such changes in the sea temperature. In fact, alterations in the best known of these centers of atmospheric permanent high or low pressures, the 'Azores high' and the 'Icelandic low' have been explained on this basis by some students. But here no general agreement has been reached, this being one of the cases (common in geophysics) where postulation has been much easier than demonstration.

The Northeast Pacific semi-permanent high is also known to shift north in summer, south in winter: and storms moving from the Aleutian region toward California sometimes linger over the Northeast Pacific for five to ten days, during which time it is only reasonable to suppose that their intensity is affected by evaporation from the water, and by the accompanying surface temperature. But very little is definitely known as to the less regular shifts in position of this or of other oceanic highs or lows, or to what extent (if at all) these shifts are caused by changes in sea temperatures.

Solution of the general relationship in this respect between sea and air is an essential preliminary to any attempt to establish whether or not oceanic variations are actually translated into weather abnormalities, except, perhaps, for localities where the climate is strictly oceanic (as on some islands), or where the wind constantly blows inward from the sea over the land.

To add to the difficulty that attends synthesis in this general field, alterations in the atmospheric centers may have climatic effects quite the opposite of what the uninitiated might expect. Thus it has been pointed out that in the colder months unusually warm water off the southeastern United States may be expected to favor oceanic low pressure and cold weather, not warm, in the Eastern States. On the other side of the Atlantic, however, any intensification of the Icelandic low may be expected to bring warm weather along the land by strengthening the southerly component of the winds. Nor is the temperature the only element of climate affected by such alterations in the winds as may follow shifts in the highs and lows, for effects on the rainfall may equally be expected. Thus variations in the mean air temperature and rainfall for India may hark back, in part, to variations in the amount of ice melting from year to year in the Antarctic Sea. Variations in the rain that falls on the south-central part of the United States may in part reflect variations in the evaporation and in the air movement from the Caribbean Sea and Gulf of Mexico; while evidence so far obtained suggests that the dampness and temperature of winds blowing in from the sea (consequently the temperature of the ocean surface for a considerable distance up wind) has a part in governing the rainfall of Southern California.

Sir Napier Shaw, in his book 'Forecasting Weather' (1923, page 160), has recently remarked that actual analysis of North Atlantic weather 'has been destructive of any hope of simple rules of weather sequence or for the movement of high and low pressure areas. The atmosphere over the North Atlantic is shown to be throughout the year in a state of turmoil which defies simplicity of description, and it is clear that something more than a process of classification is required before the sequences will become amenable to formulated law.' This statement by one of the most eminent of living meteorologists sufficiently emphasizes the difficulty with which any institution — far more any individual — is faced who undertakes serious investigation of the rôle that sea temperatures may play in the weather complex.

Although surface temperatures almost past counting have been collected in the past, it has been appreciated for many years that one of the difficulties of such investigation lies in the need for gathering reliable observations at shorter intervals, for various parts of the ocean, for only by such data would it be possible to follow, in detail, just what changes do occur in the sea.

It is pertinent here to consider how far the machinery that would be necessary for analytical investigation in this field now exists. So far as physical equipment goes, the answer would be encouraging for the North Atlantic, where steamers run regularly on so many routes that a close net of continuous oceanographic data could be obtained easily, if thermographs, barographs, and so forth, could be installed on a sufficient number of ships, and if arrangements could be made for the ships' officers to give these instruments the needed attention; also to care for the records. In fact, continuous sea water thermographs have already been installed on steamers running in various parts of the world under the auspices of several different institutions, with highly instructive results. The hydrographic services also receive a continuous stream of observations from a variety of sources, and the weather bureaus are now developing a scheme of coördinated investigation as noted on page 239. In the other oceans data are much needed from regions that lie outside the regular steamship tracks, hence cannot be obtained without special arrangement.

The most serious obstacle to the advance of knowledge as to the general relationship between sea temperatures on one hand, and atmospheric temperatures and pressures on the other, has not been any intrinsic difficulty in obtaining the marine observations, but the inability of any existing agency to undertake analysis of the enormous mass of data that has already been amassed, and that will continue to accumulate at an appalling rate if continuous observations are taken on many ships running along many different routes. For such investigation to be of any practical value whatever, this analysis is essential. It is also necessary to face not only the volume of work entailed, but also its extreme complexity, while it is obvious that efforts to work up the great mass of ocean temperatures already accumulated at several places would be an essential item in any broad-scale research in this general field. And all institutions so doing, whether governmental or private, should be encouraged to follow a common plan.

The magnitude of any such undertaking, if it were to be applied to any one of the ocean basins as a whole with the fringing lands, is quite beyond the capabilities of any private institution now existing or likely to be established. At present it is equally beyond the reach of any of the governmental weather services, for with meteorologists, as a body, unable to promise the legislatures that such analysis (even if continued for ten or twenty years) will produce commensurate economical results, it is not likely that governmental funds can be secured for large-scale investigations of this sort. Furthermore, there could be no attempt by governmental bureaus at official long-range weather forecasting based on sea temperatures (except perhaps for some locality especially favorable) until a rational basis for prediction be established by the proof that a correlation exists; until a sound method for translating such correlations into terms of weather be found; and until arrangements be made for the regular collection of the necessary data. Even assuming these requirements to be met, official forecasts could hardly be given out until the methods had been tried out for a long term of years, because if such forecasts are to engender confidence, they must be verified by the event in a substantial majority of cases.

These difficulties unite to make this a field in which fertile results may be soonest expected from what is known as the 'case system' of investigation, while the extreme complexity of the basic problem makes it essential that the simplest cases be the first attacked, thus approaching as nearly as possible to the laboratory method. Furthermore, the impossibility (if we are to be intellectually honest) of promising immediate economic benefits therefrom, makes research institutions particularly appropriate centers for certain aspects of such work, in coöperation with the governmental weather bureaus.

The very encouraging progress that has been made in the experiment now being carried out by the Scripps Institution (just mentioned) corroborates this view, for it appears, at present, that temperature departures in the various parts of the Pacific are one of the classes of indicators that can be combined into cumulative forecasts of seasonal rainfall and perhaps of temperatures for Southern California at least, while recent investigations show a sequence of pressure and temperatures across the Pacific Ocean, which suggests the effects of a transportation of heat by ocean currents. And while much work yet remains to be done to uncover the effect of other factors that are undoubtedly concerned, if the system is to be placed on an assured basis, even for this specially favorable locality, the suggestive results of the attempt, to date, not only justify the continuation of this line of work in Southern California, but point the need of investigations of the same sort in other representative regions chosen on the basis just stated (page 253). The relationship that rainfall in Ecuador and northern Peru bears to ocean temperatures off that coast offers a very promising case for study. Other vantage-points that seem favorable, because interpretation promises less difficulty there than in most parts of the world, appear to be the southwest coast of Africa, the northeastern Asiatic seaboard, northeastern Brazil, southern Alaska, and the Gulf and South Atlantic seaboards of the United States.