productivity. The Cat Cay Station in the Florida Straits would lie on the edge of this biological region, whereas Bermuda would lie outside of it.

The obvious corresponding feature of the seasonal cycle of chlorophyll *a* is the decreasing amplitude of the cycle from 0.0-3.0 mg/m^3 in the North Sea to 0.0-0.3 mg/m^3 in the Florida Straits, with Bermuda intermediate. It is important to note, however, that even at the Cat Cay station there is a seasonal cycle with a small winter maximum. This increase, since it does not appear to have been caused by nutrient enrichment, may be partly a consequence of adaptation for lower light due to the greater depth of the layer in which the plants are mixed and to the somewhat lower solar radiation in the winter.

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What Oceanography Means to Fishermen

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Abstract

Oceanography has provided knowledge of average conditions in the ocean and the processes maintaining them in equilibria. Augmentation of oceanographic effort now under way may be directed in large part toward attaining prediction capability especially of departures from average conditions in the upper mixed layer and the thermocline. This may be accompanied by parallel research effort on the ecological requirements and behavior of food fish and shellfish to provide understanding of their responses to environmental change. Combined, these efforts will have practical meaning to fishermen if it enables them to eliminate time lost in scouting for fish and in fishing on less than optimal concentrations, and so lower their cost of fishing and keep their product competitive with agricultural products and imported fish.

FROM A DISTANCE OF SEVERAL THOUSAND MILES I have noted with admiration the growth of interest in, and advancement of, the studies of the ocean and its fishery resources in the Gulf and Caribbean and adjacent Atlantic that have occurred during the last several decades—stimulated, I am sure, by the annual meetings held by this Institute. I am grateful to have this opportunity of participating in this one.

Knowing that expansion of oceanographic effort has recently assumed a more important place in the national policy of this country and that one of the reasons, among many others, given for this is "to get more food from the sea," one may well ask "what does this mean to the fisherman?" Well known to all in this room, and felt most keenly by the fishermen among us, is the difficulty the fisherman is having in selling the food he garners from the sea at a price that will keep him in business.

This is getting more difficult every day. Advances in agricultural research and the wider use of machinery have combined to make farming vastly more productive per acre and per man than heretofore. Technological advances in processing farm products have made them more attractive to the housewife. The competition in the market from farm products becomes ever more pressing on fishery products. Added to this is the increasing competition from imported fishery products, an inevitable consequence of our national policy of encouraging international exchange of goods.

Under these circumstances, what does oceanography mean to the fisherman? Obviously it cannot give his product a preferred place in the market. If it is to mean anything to him, beyond giving some intellectual satisfaction from knowing more about the sea on which he sails and from which he extracts a living, it must enable him to catch his fish at less cost, and with no degradation in quality.

Can oceanography help him do this?

To examine this question, we must first inquire what oceanography is, its present state and its future prospects.

Broadly speaking, oceanography is the study of the ocean, its boundaries, its contents and the dynamic processes going on within it. This is a very broad field of study and inherently difficult because most of the ocean is inaccessible except by instrumented probes. The number of dollars, ships, and men devoted to this study in the past have been far too few, in proportion to the size of the ocean and the inherent difficulties of studying the problems it presents. Progress has been painfully slow, and for this reason oceanography, we must admit, has not held much practical meaning to the fisherman.

A generation ago the major motivation and major support for oceanography came from fisheries. This is now undergoing rapid change. With the advent of the submarine as a decisive strategic weapon in World War II, our Navy has become aware that an intimate knowledge of subsurface conditions and events is vital to the successful tactical employment of this weapon and successful tactical defense against it. There, too, is an increasing awareness that improvement in short- and long-range weather forecasts depends on a fuller understanding of energy exchanges between ocean and atmosphere. Disposal of wastes, both ordinary and radioactive, increasingly involves the use of the ocean.

All of these combine to augment the motivation and the support for study of the ocean. Progress will accelerate, and understanding sufficient to predict ocean conditions will be achieved, many times sooner than could be expected even a short time ago.

What does this mean to the fisherman?

Some say that fishermen are using century-old hunting methods; that oceanographic knowledge will enable the fisherman to employ entirely new principles to concentrate the fish and scoop them up almost automatically. Some say that we ought to forget the fish at higher trophic levels and concentrate on those at lower trophic levels; or even go farther down the food chain and harvest the plankton of the sea, there is so much more of it. Some say that oceanographic knowledge will enable us to control the ocean, or some parts of it, fertilize it, plant the right kinds of food fish (or shellfish), weed out the trash fish, and produce much more fish (or shellfish) with much more regularity and of much higher quality, just as farmers are doing with land plants and animals.

I do not disagree with these ideas and assertions. But I do not think that these promises will be fulfilled by sudden, magic breakthrough in the near future, or during the life-time of anyone in this room. Rather, I suggest that fishermen are already taking advantage of advanced technologies as fast as they become practical. They are using the echo-sounder to locate the bottom and concentrations of bottom fish, and some have, to their sorrow, tried to use sonar to locate fish schools even before it was fully practical. They have adopted nylon cordage for lines and nets and are continuously employing more machine power to replace man power.

I suggest that for a long time to come, it will be more efficient to let the food fish concentrate the organisms of the lower trophic levels, convert them into flesh and then catch the food fish when they concentrate, as most fish do at some times and some places.

I suggest that fish farming in the open ocean will require the control of such large forces and involve the use of such large sources of energy, that it lies in the very far distant future. But fish and shellfish farming in partly enclosed estuarine situations is already practiced and can be greatly extended if we fishery people get around to it before other activities of mankind pre-empt the estuaries for other uses—as for instance, waste disposal.

In other words, I suggest that the effect of progress in oceanography on fisheries will be a slow evolutionary process, and wish to explore today, some advances that appear feasible in the near future. These have to do with the cost of catching fish, by present conventional, or only moderately improved, methods.

Most of these costs are inescapable and many are rising. But one of the large factors in the cost to the fisherman, per pound, of landing a load of fish at the dock is how long it takes him to find a concentration of fish and how much he can catch out of the concentration after he has found it.

Obviously it would mean much to the fisherman if oceanography could supply information that he could use to find fish more quickly, in concentrations yielding good catches and do this reliably, thereby substantially lowering his cost of fishing.

Frankly, I do not know whether oceanography can do this; or, if it can, how soon.

Oceanography has already given us an understanding of the average marine environment. We know that the ocean is essentially made of two layers; a thin restless upper layer perhaps a hundred fathoms deep overlaying the continental shelves, and farther offshore, floating on top of a very thick sluggish layer extending to the sea bottom. The upper layer is ever changing; warmed by the sun, mixed by the winds, and containing the well-known fast-flowing ocean currents, and it is the zone where one-celled plants utilize the energy of sunlight to produce living material that sustains all animal life in the sea from the tiny copepods to the great whales.

The lower layer is eternally cold, shrouded in perpetual darkness and hardly changing with seasons or centuries. By the decomposition of waste matter raining down from the productive layer above, it becomes the reservoir of oceanic fertility.

Separating the two layers is a zone of rapid decrease in temperature, the thermocline, which varies in depth both in time and space. It may form a barrier to descent by most epipelagic fishes. It prevents recharging of the upper mixed layer with nutrient salts from the reservoir below except when and where it is disrupted by upwelling, convective mixing from winter cooling, and turbulence of current boundaries. Consequently, over much of the deep ocean, life is sparse, but at the locations of thermocline disruption it can be very rich.

Moving horizontally across the ocean we encounter water masses with different physical and chemical characteristics, containing different biological regimes, and whose boundaries sway with season and vary irregularly from year to year.

These vertical and horizontal features determine the abundance and distribution of the life in the sea. Through evolutionary time, each kind that has survived until now has become adapted to some particular combination of conditions; and it has developed patterns of behavior, of migration, of feeding and of spawning that enable it to respond successfully to the changes in the undersea climate and to follow the conditions suited to it when they become displaced by undersea climatic irregularities.

To find good concentrations of fish in a catchable state of behavior, and to do this regularly, oceanographers and fishermen must know what conditions to look for and where to look. They must know not only the average conditions, but the variations from them and be able to predict these variations.

There is not time to enumerate the different attacks on these problems being made by many research groups.

Instead, I will attempt to convey some indication of the nature of the problem, its difficulties and some notion of the state of progress in one approach being followed at our Bureau of Commercial Fisheries Biological Laboratory at Stanford. Our motivation, of course, is fishery oriented and our approach is to find out by examining the historical record what changes have taken place in the North Pacific ocean climate in the past and how these have affected the fisheries.

In the eastern Pacific we have experienced one marine climatic regime of relatively cool conditions over ten years duration followed by another of relatively warm conditions of about three years duration. As we might have expected, if we had anticipated it, there were concurrent displacements in the centers and boundaries of fish distribution.

The change from the ten-year regime to the three-year regime took place between 1956 and 1957. The transition occupied a number of months but by August of 1957 had reached a stage where its nature became quite evident in the ocean-wide field of sea-surface temperatures. The field for August 1956 is shown in figure 1.

I should say at this point, that the reduction of a vast number of temperatures to chart-form is owing to the efforts of my associates, J. F. T. Saur, Oceanographer, and L. E. Eber, Meteorologist, who have now produced such charts for each of the 24 months of 1956 and 1957 which are to be published as the first installment of an Atlas of Pacific Sea Surface Temperatures for as long a series of years as the historical data are of sufficient abundance and reliability to describe the temperature field.

As we would expect, the temperature field reflects basically the poleward decline of temperatures upon which is superimposed the effects of the current system in transporting water and its heat content. On the west we find warm water extending northward as the result of transport by the Kuroshio, and cold

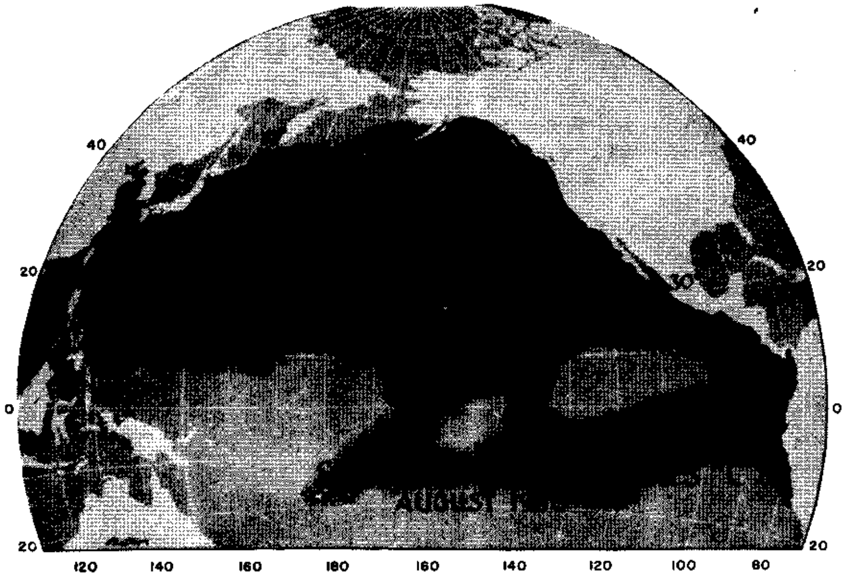

FIGURE 1. The field of sea surface temperatures over the North and Tropical Pacific in August 1956, in °C.

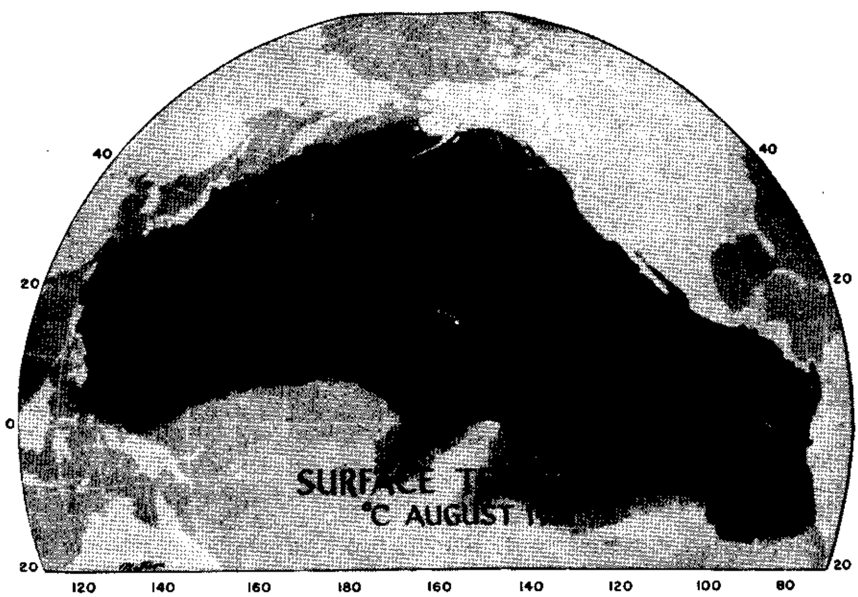

FIGURE 2. The field of sea surface temperatures over the North and Tropical Pacific in August 1957, in °C.

water extending southward as the result of transport by the Oyashio, packing the isotherms closely just north of the elbow of the Japanese island of Honshu.

Eastward we find the isotherms spreading apart as the north Pacific west wind drift approaches the American coast and branches north and south conveying warmer water northward into the colder water of the Gulf of Alaska Gyre and colder water southward as the California Current along the Washington, Oregon and California coasts into the area that otherwise would be warmer.

The same general picture is portrayed in the temperature field for August 1957 (Fig. 2). But note that there is a closer packing of isotherms off Japan and wider spreading off the American coast. Also the 15° and 20° isotherms undulate in opposite directions in the two years.

The differences are more easily seen when we subtract the 1956 temperature field from that of 1957, giving us the difference between the two Augusts (Fig. 3).

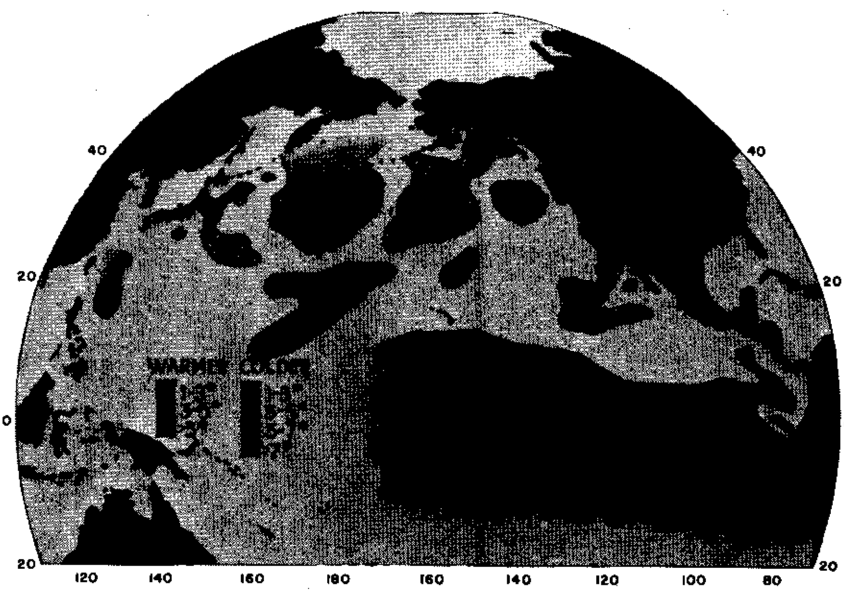

FIGURE 3. The change in sea surface temperatures over the North and Tropical Pacific from August 1956 to August 1957, in °C. Areas warmer in 1957 than in 1956 are marked with a plus sign; those colder in 1957 than 1956 are marked with a minus sign.

We see in 1957 in the temperate latitudes that a large area was much colder in west and another large area much warmer in the east. Most of the rest of the Pacific was warmer in 1957, but more moderately so, except off Peru where temperatures over a vast area reached heights approaching warm El Nino conditions.

These temperature differences in the transition zone between the subarctic water mass and the subtropical central Pacific water span a wide range, from over 7°C colder in the west to more than 5°C warmer in the east, a total of 12°C or 21°F. Also large areas are affected, measured in the millions of square nautical miles.

As warm-blooded land animals we cannot intuitively appreciate what this might mean to the cold-blooded animals of the sea.

Experiments have shown that fish can sense temperature changes as small as 0.05°C and respond to such slight changes. It is also well established that the metabolic activity of cold-blooded animals slows down with a lowering of environmental temperature and speeds up with a rise in environmental temperature. This profoundly affects the physiology of the animal and its activity.

Thus, no matter whether the fish and other sea organisms shifted when there were such large temperature changes, or whether they remained in the same areas and underwent the physiological effects of the different temperature regimes, there would still be major effects on the fishery.

We know that in 1957 a number of fishes responded to the more moderate warming along the American coast. For instance, the sockeye salmon forsook their usual approach through the Straits of Juan de Fuca to the Fraser River and approached around the northern end of Vancouver Island and through Johnston Strait. In 1958, when the difference became more extreme than in 1957, sardines were taken in Monterey Bay by the tonnages unknown since 1951. Barracuda and yellowtail, whose centers of abundance are off Lower California, became exceedingly abundant in southern California waters. The tropical tunas, skipjack and yellowfin tuna spread northward into southern California waters and southward to the bulge of Peru, leaving a relative scarcity in the middle of their range.

We know of these temperature changes and fish responses now; we were only dimly aware of them at the time, and certainly could not have predicted them.

Prediction capability requires a knowledge of the processes that cause such changes. We have begun to study this question and expect to pursue such studies more intensively.

From the mean atmospheric pressure fields that L. E. Eber is studying, it is apparent that the atmospheric circulation in January and August 1957 was markedly different from the corresponding months of 1956. These differences were of the kind and approximate magnitude to have produced the observed differences in sea surface temperature in the temperate latitude area either by wind-driven movement of the surface water, or by divergence-convergence processes, or a combination of both. The less pronounced changes in the other parts of the Pacific have not yet been studied.

If such changes are produced by altered atmospheric circulation and persist as they did in 1957, or even if they do not persist, but lead time is offered by reliable extended weather forecasts, it appears quite within the near future state of our understanding to predict these shifts in oceanographic conditions and perhaps some of the consequences to some of the fisheries.

However, this appraisal may well be over-optimistic. There is a grave lack of information on the variable thickness of the upper mixed layer. The estimates of atmospheric effects mentioned above involved assumptions rather than data on the subsurface temperature structure. Such data probably can be secured with sufficient continuity in time and space only by establishing a network of deep-anchored unmanned buoys with automatically operated instruments reaching down through the mixed layer and with telecommunication capability.

With defense and weather forecasting needs for gathering nearly the same kind of information as are wanted for fishery purposes, it seems that such a system may eventuate in the near future in at least some parts of both oceans. Given such information-gathering facility, plus a reasonable amount of time and adequate research effort, it is not outside the bounds of possibility that at least the most marked changes of large extent and moderate duration can be predicted.

The problems of monitoring and predicting more transient changes of smaller scale are somewhat different. Oceanographic research is under way on these problems at a number of laboratories. The sensing instruments and the principles for translating the data into practical operating information will stem from this research.

It is intended, by the example and by this discussion, to convey the kind of information gathering and research required to predict environmental changes. Their use in predicting the time and place of fish requires parallel information gathering at sea and in the laboratory on the behavior of fishes and the forms they feed upon. Time does not permit elaborating on this equally large and difficult area of endeavor. A beginning has already been made at several research centers and it is anticipated that such work will be given the expanded support it requires in order to be fruitful.

The two branches of effort, the physical and the biological, are progressing toward the goal of lessening the cost of catching fish. With this brief cursory review of the state of this effort, it will be left to each of you to make his own estimate of what oceanography means to the fisherman or what it may mean in the future, and when.