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PRESENT STATE OF OUR KNOWLEDGE AND IGNORANCE CONCERNING THE OCEANOGRAPHY OF THE GULF OF MAINE

by

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PRESENT STATE OF OUR KNOWLEDGE AND IGNORANCE CONCERNING THE OCEANOGRAPHY OF THE GULF OF MAINE

I. Physical Oceanography

Both the gross distribution of the physical and chemical properties and the general circulation of the Gulf of Maine are fairly well known as a result of the observations of Bigelow (1927) [1/], Gran (1933), Rakestraw (1938 and 1936), Watson (1936), Redfield, Smith and Ketchum (1937), and Redfield and Keys (1938). Although a large amount of oceanographic work has been conducted in the Gulf of Maine, there are serious deficiencies in areal and seasonal measurements and in the evaluation of the mixing processes. More recent studies by Day (1958) and Bumpus (1960) have added some detail to our knowledge of the non-tidal circulation and have shown that the July-August pattern as described by Bigelow (1927) evolves with the seasons and that the circulation may be strongly modified by winds. It must be concluded, however, that although certain characteristic features of the circulation and of the distribution of temperature and chemical constituents have been demonstrated, it can not be claimed that even with improved instrumentation and navigation that much additional understanding of the circulation has been gained since the pioneer studies of Bigelow.

1/ For references not given in the text, see Laboratory Report Number 62-6.

Before we can hope to increase our understanding of coastal circulation and its effect on the fisheries we must find answers to the following questions:

(1) By how much does land drainage have to change before the normal environment of coastal water is seriously effected?

(2) How abnormal does the weather have to become before the winds produce a corresponding change?

(3) How important to the large-scale exchanges of coastal and oceanic currents are the variations of the deep, offshore currents?

The available temperature and salinity observations cannot answer these questions. The data consist of spot observations, separated widely in time and usually also in space. Observations from some of the extreme winters (for example 1918 and 1931) are entirely lacking. While the inshore winds and inflow of several of the rivers are known continuously for a good many years back, the only reasonably continuous oceanographic data are some sea surface temperature records close to the beach, and these obviously reflect local weather. Offshore on the bottom where the main commercial fisheries are located, we have no continuous information, nor do we have records of the variations in the offshore component of the upper half of the water column.

The problems involved in studying coastal circulation have been discussed by Iselin (1940, Trans. Amer. Geophys. Union, 1940:

347-348 and 1955, Pap. Phys. Oceanogr. Meteorol., 8: 1-40) and the following summary of these problems and methods of surmounting same is based in part on his observations and recommendations.

In most parts of the Gulf of Maine, the balance between static and dynamic forces is too delicate to admit to simple solution by analysis based on occasional observations. Not only are there complications resulting from short-period internal waves, but over most of the area the velocity of tidal currents far surpasses that of the gradient flow so that the assumption of a steady state of motion is most questionable. In addition, the relatively great difference in depth between stations introduces further difficulties in analysis. The mixing processes at the edge of the continental shelf where coastal water and oceanic waters meet are even less well understood and on none of the sections so far examined, have sufficiently closely spaced salinity and temperature observations been secured for one to be certain of the changes in the T-S correlation curve as one moves from typical coastal water to typical slope water. Not only are these small scale mixing processes near the 100 fathom curve complex and poorly understood, but so are the large scale mixing processes which appear to be of much greater biological significance. No network of stations in this critical area has been sufficiently closely spaced to permit only one solution to the contouring of the physical properties. It is yet impossible to describe any sector near the edge of the continental shelf in three dimensions in a reliable manner.

The productive fisheries in the Gulf are located in areas of relatiṿely weak gradient flow and in areas where it is hopeless by ordinary water bottle technique to secure physical observations that will provide information on currents to supplement biological surveys. But in an area such as Georges Bank, for example, the gradient flow is usually peripheral and it is the cross current transfer (movement of fresh water out along the surface and of salt water in along the bottom) that is much more biologically significant than the more obvious flow at right angles to the pressure gradient. Superimposed on this more or less steady interchange of coastal and oceanic water (which proceeds at an average rate of as much as 10 per cent per month) are short term, but significant interchanges caused by winds and large frictionally driven eddies which carry considerable masses of coastal water offshore near the surface and which are compensated for by an equivelant movement inshore of more saline water along the bottom. It is these major disarrangements of coastal circulation that appear to have the most important biological consequences as regards the distribution of planktonic organisms.

None of the three standard techniques for studying currents namely, water bottle observations, current-meter measurements, and drift bottle experiements, provide in themselves the sort of information which is needed to study these mixing processes. Without the help of entirely new techniques it has seemed up to the present time, to be too difficult an observational problem although it has been clear for some time (Iselin, 1940 and 1955) that the important clues towards an understanding of the circulation in the Gulf of Maine were to be found in this zone. Two approaches, one involving short-term in situ studies of the actual movement of a given body of water and the other long-term, time-series studies of the fluctuations of the two primary variables in coastal circulation, namely wind and river run-off are suggested.

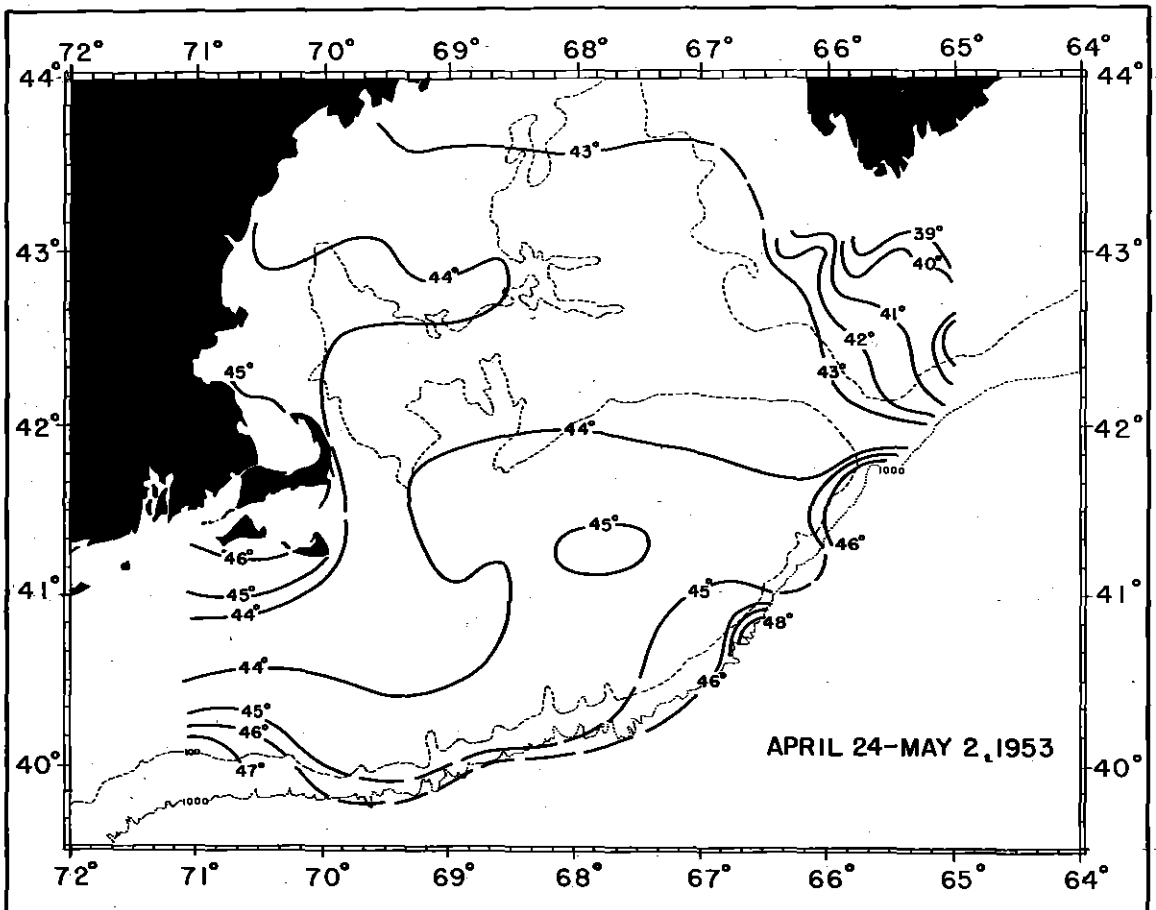
In the first type study it is necessary for the observer to move with the water mass being studied to eliminate variables caused by strong tidal oscillations. This can be accomplished through the use of marker bouys anchored with a drag at various levels and neutrally bouyant buoys. The buoy movement across current from day to day would give a measure of mass lateral transfer as has been demonstrated by Bumpus et al. (1957) and by Colton and Temple (1961), while repeated water bottle samples would permit studies of changes in the T-S correlation in a given mass of water and would provide data on the coefficients of lateral and vertical turbulance.

The second approach would emphasize the more systematic collection of continuous records of temperature, salinity, winds, and river runoff at as many fixed points along the periphery of the area as possible (this is currently being done on a contract basis by the Woods Hole Oceanographic Institution). In addition time-series observations of surface winds and of temperature, salinity, and currents at the surface and at depths at strategic locations in the offshore waters of the Gulf of Maine are needed to supplement data collected at shore stations and during semi-synoptic research vessel cruises.

Data collected during the many research ship cruises of the Gulf have shown that continuous observations are essential for the understanding of circulation. For example, the rapidity of temperature change during the period of vernal warming is such that a synoptic picture of the temperature distribution cannot be obtained from ship surveys. An idea of the magnitude of change in surface temperature in the Gulf of Maine during the spring can be obtained from comparing plots of surface temperature during two phases of a two-week cruise by the Albatross III during the latter part of April and the early part of May 1953 (fig. 1). The surface temperature had changed to such a degree between the first and second circuits of the area, that it was impossible to plot the surface temperature data in terms of a two-week cruise.

Figure 1.--Surface temperature distribution in the Gulf of Maine during April and May, 1953

In addition, it is essential to our understanding of circulation to determine when mass interchanges of coastal and oceanic water occur. For example, Redfield (1941) has demonstrated a correlation



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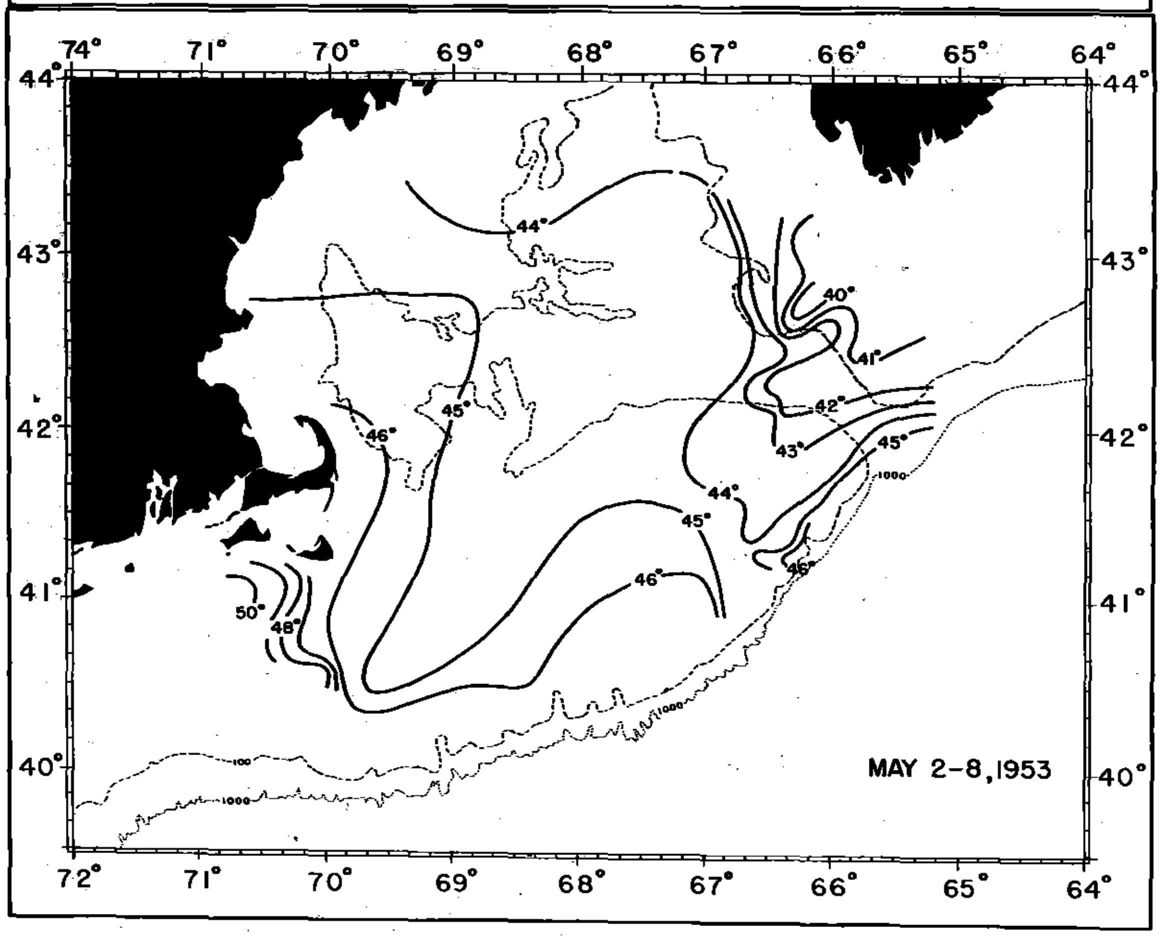

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between salinity and productivity in the Gulf of Maine and the annual inflow of low salinity and relatively barren water from the Scotian Shelf, Colton (1959) has demonstrated that intrusions of warm oceanic water onto Georges Bank can cause appreciable mortality of boreal fish eggs and larvae, and Walford (1938) and Colton and Temple (1961) have shown that many fish eggs and larvae of commercial fish species are carried away from Georges Bank by the offshore movement of surface water. However, to date our knowledge of such mass movements of water is very limited and based principally on inferences drawn from biological conditions. Systematic annual observations would give us information on the time, magnitude, and frequency of such intrusions and excursions and serve to test these relations. Should they prove general, such information might lead to a better understanding of the yearly fluctuations in commercial fisheries.

Continuous observations in the offshore waters of the Gulf of Maine would require the establishment of unmanned buoys to measure various parameters continually at strategic points. The necessary instrumentation for recording a sufficient range of parameters (temperature, salinity, currents, and wind) is available, but to date, unmanned buoys for mooring in an area of strong tidal currents such as are found on Georges Bank have not been developed to a satisfactory level of reliability in staying moored. Studies of this problem are being undertaken at several laboratories and it seems reasonably between salinity and productivity in the Gulf of Maine and the annual inflow of low salinity and relatively barren water from the Scotian Shelf, Colton (1959) has demonstrated that intrusions of warm oceanic water onto Georges Bank can cause appreciable mortality of boreal fish eggs and larvae, and Walford (1938) and Colton and Temple (1961) have shown that many fish eggs and larvae of commercial fish species are carried away from Georges Bank by the offshore movement of surface water. However, to date our knowledge of such mass movements of water is very limited and based principally on inferences drawn from biological conditions. Systematic annual observations would give us information on the time, magnitude, and frequency of such intrusions and excursions and serve to test these relations. Should they prove general, such information might lead to a better understanding of the yearly fluctuations in commercial fisheries.

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Once the influence of winds and the variations of river inflow have been properly assessed, the causes and importance of the large scale mixing processes at the edge of the continental shelf have been worked out, and the relationship of offshore and inshore conditions have been determined, it should be possible to go over the long-term meteorological and hydrographic data to determine: (1) when and where the coastal environment was seriously disturbed, (2) how strong and persistent the winds and variations in river inflow have to be to cause a significant disturbance in the normal exchange between coastal and offshore water and, (3) if these environmental changes are of sufficient magnitude to account for the fluctuations in the abundance of commercial fish.

The present situation in coastal oceanography and the basic problems to be solved were summarized by Iselin (1955) as follows:

(1) The available data are inadequate to establish how variable the coastal environment may be because of fluctuations in its principal energy source, namely land drainage.

(2) So far as the oceanic currents are concerned, it is believed that the winds, either directly or indirectly, supply most of the energy. Considerable variations in the offshore currents are known to exist, but to what degree these influence the inshore currents remains obscure.

(3) Coastal currents, on the other hand, for the most part, operate without direct help of the winds, yet strong and prolonged winds could be a cause of important variations in environment from the biological standpoint, especially for fishes which spawn near the edge of the continental shelf.

(4) Occasional surveys of the distribution of temperature, and salinity are unlikely to provide more than a limited understanding of coastal currents, for the classical theories of physical oceanography assume steady state-conditions and, because of tidal currents, this simplification is far from being justified in coastal waters.

(5) Continuous observations, even of a rather simple sort at well selected points over the continental shelf, should provide means of evaluating the influences of variations in river inflow, of the local winds, and of the offshore currents. Fortunately new means of obtaining such observations have been developed in recent years.

(6) Once these factors have been evaluated, the major environmental fluctuations can be probably deduced as far back as the weather record extends.

(7) The general distribution of temperature and salinity in coastal waters indicates that, except briefly in mid-winter, it operates as a three-layered system. The warm wind-stirred surface layer and the cold stable layer just below both have offshore components, but probably quite different ones. Near the bottom, and especially where gullies and drowned river valleys exist, there is an inshore component. By moving up or down in the water column an organism can be carried either inshore or offshore, by the large scale interaction of coastal and oceanic water it can either be carried up-coast or down-coast. From the biological standpoint, it is important to establish how steady or how variable these current systems may be.

II. Biological Oceanography

The observations of Bigelow (1927), Gran and Braarud (1935), Fish (1936a, 1936b, and 1936c), Fish and Johnson (1937), Bigelow, Lillick, and Sears (1940), Lillick (1940)and Sears (1940) have furnished us with a general picture of the distribution and species composition of phytoplankton and zooplankton in the Gulf of Maine. In addition there is some information on the relative abundance of plankton in various regions (Bigelow, 1927, Bigelow, Lillick, and Sears, 1940, Riley, 1941, and Clarke, Pierce and Bumpus, 1943), on the basic productivity in various areas (Lillick, 1940, Sears, 1941, Riley, 1941, 1946, and 1947, and Clarke, 1946), and on the ecological relationships of individual species and of plankton communities (Clarke, 1933, 1934a, and 1934b, Redfield, 1939 and 1941, Redfield and Beale, 1940, and Clarke, Pierce, and Bumpus, 1943).

However, although the general biology of the waters of the Gulf are fairly well understood, there is, as in the case of physical oceanography, a basic need for continuous observations at fixed points and short-term, synoptic research ship observations to obtain more detailed information on the regional and seasonal fluctuations in abundance and distribution of zooplankton and phytoplankton, to evaluate the general features of productivity, to obtain a more detailed picture of the food chain, and to further our understanding of the effect of circulation on the ecological structure of the plankton communities.

The problems of biological sampling is considerably more complex than that involved in studying the distribution of physical properties for: (1) the plant and animal organisms are not randomly distributed either vertically or horizontally, (2) many zooplankters undertake extensive diurnal vertical migrations and the extent of these vertical migrations varies with species and stage of development, (3) many of the larger zooplankton species are capable of avoiding slow-moving collecting gear during the daylight hours, (4) no single piece of gear or standard method of tow is suitable for sampling all the various species of phytoplankton and zooplankton, and it is not possible to obtain synoptic time-series biological data through the use of unmanned buoys as the necessary instrumentation has not been developed for measuring the various parameters of the biological regime. Nevertheless, the need for concurrent physical and biological observations is paramount for an understanding of the interactions of biological and physical processes involved in the production, distribution, and fluctuations of the Gulf of Maine populations.

It appears that the most feasible method of obtaining continuous biological data at the present time would be through a program of Continuous Plankton Recorder collections based on runs made by commercial and government vessels within the Gulf of Maine and in contiguous waters. The Scottish Marine Biological Association has had such a program in operation for a number of years in the North Sea and Northeastern Atlantic. In their analysis of these data, they have paid particular attention to the most abundant species of zooplankton and phytoplankton and to indicator organisms and have demonstrated that such sampling is most valuable for studies of fluctuations in abundance, distribution, and species composition of plankton and that the species composition of the whole plankton community can be used to provide indications of hydrographic and other environmental changes. Such a program combined with periodic research-ship surveys to provide semi-synoptic information of a greater range of biological parameters and over a greater range of depths for the whole area as well as detailed information on the species composition and ecological relations in specific regions should supply the necessary data needed to answer the following questions.

(1) How does the plankton, apparently helpless in the face of water movement, maintain descrete populations?

(2) What are the possible relationships between the species distribution of plankton organisms and the distribution of physical and chemical properties such as temperature, salinity, and nutrients?

(3) What are the factors that limit the distribution of plankton communities, regulate their abundance, determine their vertical structure, and control vertical distribution and migration?

(4) How does the distribution, species composition, and abundance of plankton vary with seasons and years and what is the relation of the changes in these parameters to the changes in the distribution, species composition, and abundance of fish?

(5) What is the relation of the seasonal outbursts of phytoplankton and zooplankton to the time of spawning of fish?

(6) What effects do fresh water drainage, inshore movement of oceanic water, variation in solar radiation, and wind driven circulation and mixing have on the basic productivity of coastal water?

(7) What is the rate of formation of organic material by the phytoplankton and the rate of its subsequent transfer through the food chain?

(8) What species of zooplankton serve as food suppliers, as predators, and as indicators of water movement and type?

III Fishery Hydrography

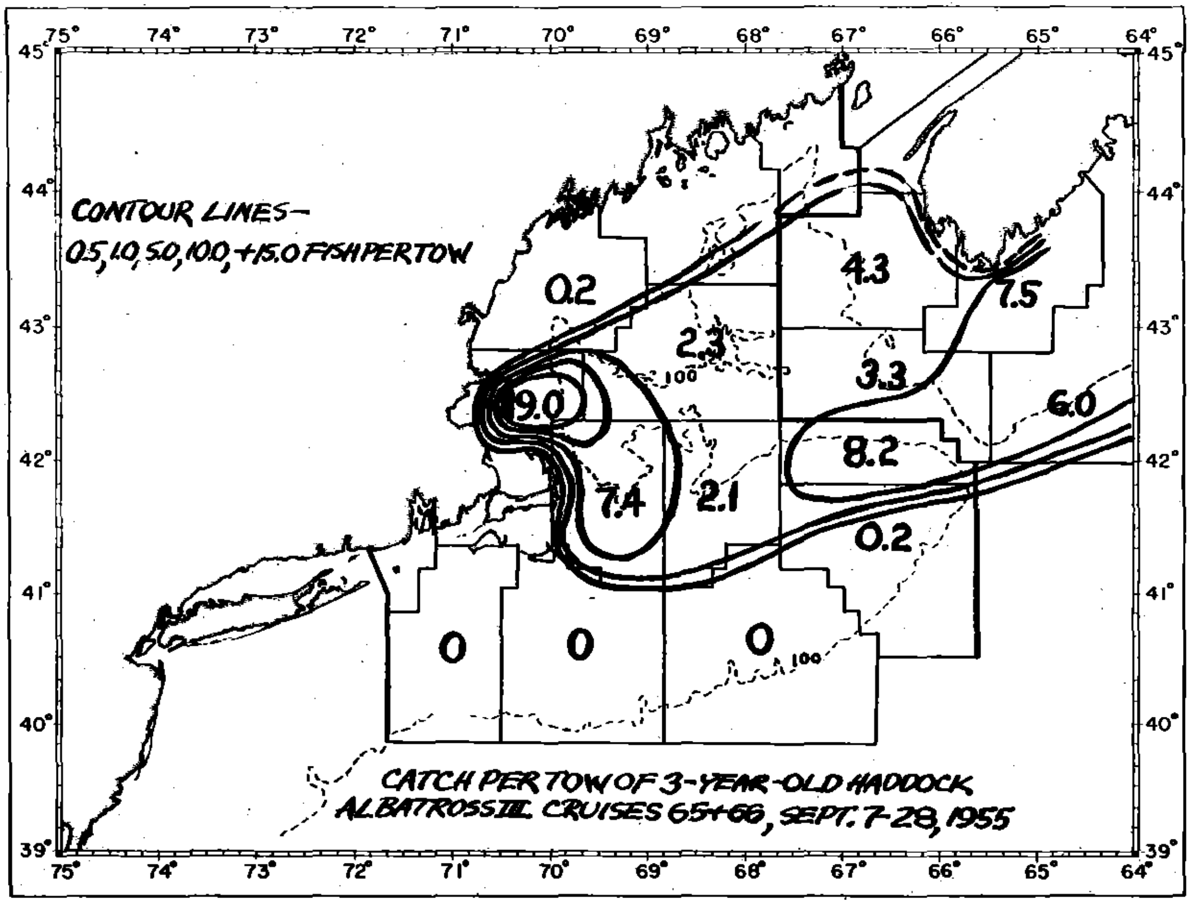
A description of the fishes of the Gulf of Maine and the details of their distribution and relative abundance, and the more significant facts of their life history are given by Bigelow and Schroeder (1953). In addition, the landings of the commercial vessels provide us with a general picture of the seasonal and regional distribution of certain species of commercial groundfish in the Gulf of Maine, and a rough measure of their fluctuations in abundance. But, because the effort of the commercial fleet is restricted to limited areas and depths, and because the areas fished vary between seasons, these data only indicate the seasonal variations in abundance within an extremely limited sector, and do not furnish an accurate picture of the distribution and abundance over the whole area. In addition, up to the present time only the catches of groundfish from a limited number and size category of vessels fishing in a limited depth zone have been used in estimating the age composition and abundance.

Research ship surveys show that in the case of the haddock fishery the location of the major effort of the commercial fleet at any given time does not necessarily reflect areas of greatest abundance of all age fish (Colton, 1955). In general, the commercial vessels tend to concentrate in areas where there are relatively large numbers of young haddock (2 and 3-year-olds), where there is a minimum chance of damaging their gear, and where tradition dictates the fish are located. The result of this regionalization of effort is that considerable areas of the Gulf of Maine are not sampled by the commercial fleet and that a true picture of the distribution, abundance, and age composition over the area as a whole or in any of its subdivisions cannot be obtained from an analysis of their landings.

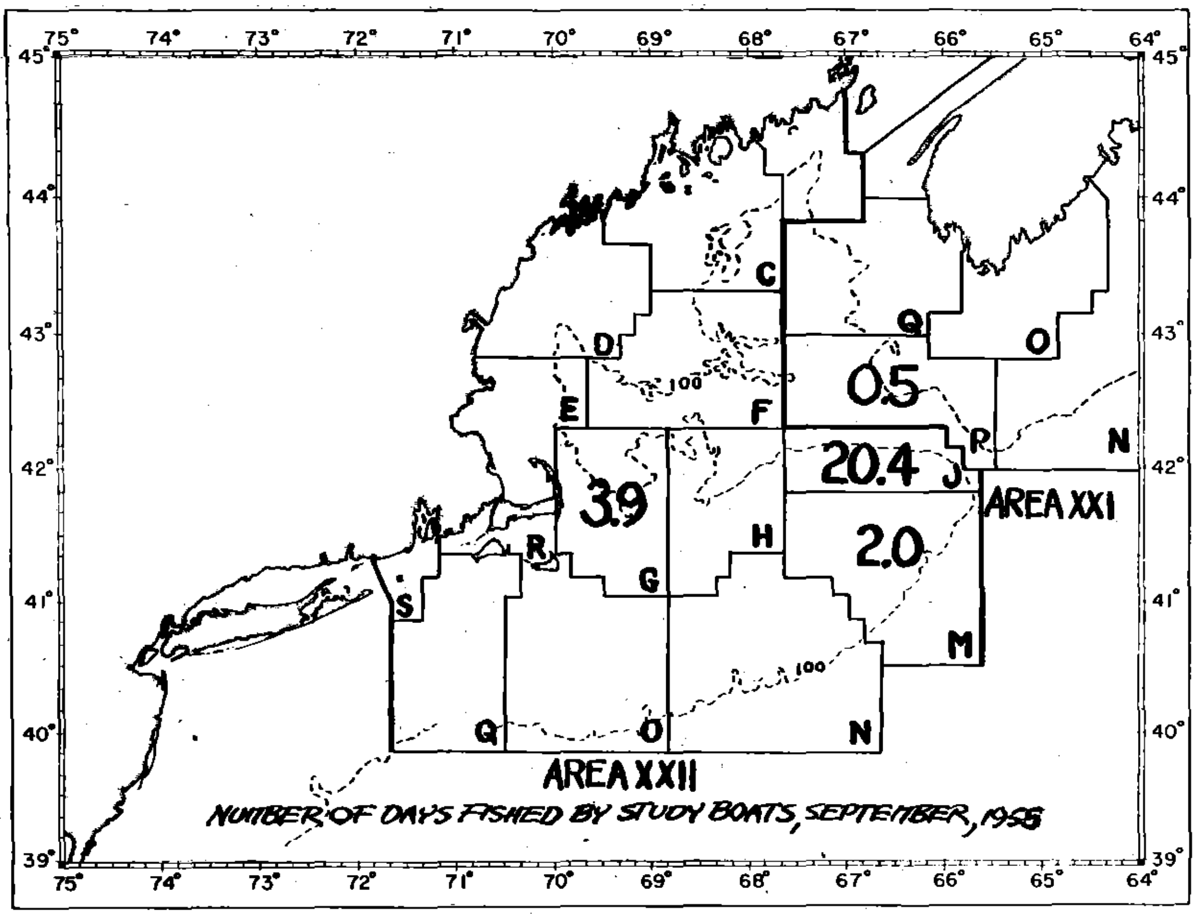
To illustrate the effect of this sampling bias on the part of the commercial fleet and the further bias introduced by only including data from a selected group of trawlers fishing in a restricted depth zone (30-60 fathoms), a comparison of the regional effort of the study boat fleet in terms of the number of days fished in the various statistical subareas in the Gulf of Maine during September, 1955 and the relative abundance of 3-year-old haddock in these subareas as determined from an Albatross III survey during this same period is given in figure 2. Three-year-old haddock were selected for this comparison for it is on the basis of the relative abundance of this age fish that estimates of brood strength are determined.

Figure 2. --Study boat effort and distribution of 3-year-old-haddock September, 1955.

It is seen that not only was the effort of the study boat fleet concentrated in a limited area, but that they did not fish in the region where 3-year-old haddock were most abundant at this time (Subarea E). This regional bias is still apparent when study boat effort data for all depths is included and distorts the picture of the distribution and



CATCH PER TOW OF 3-YEAR-OLD HADDOCK
ALBATROSS III CRUISES 65+66, SEPT. 7-28, 1955



NUMBER OF DAYS FISHED BY STUDY BOATS, SEPTEMBER, 1956 abundance of all age haddock.

In addition, the trawls used by the commercial boats do not representatively sample the younger haddock (zero-ring and one-year-olds). It is the abundance and distribution of these age haddock that are most valuable for predicting the brood strength of a given year class before entry into the commercial fishery. Therefore, it is essential to our understanding of the seasonal and yearly fluctuations in the distribution and relative abundance of individual fish species and of interspecies relationships that we conduct census surveys of these populations. Such surveys have been conducted sporadically in the past, but it is necessary that these surveys be taken on a seasonal basis and over a considerable span of years.

Such survey cruises are time consuming and at least a month is required to sample the area in question adequately and because of the transient nature of the populations of fish the data obtained is often misleading. In addition, an analysis of the past survey data has shown marked differences in the day and night catch of some species of fish and a variation in this day and and night ratio with age. Unless some correction factor can be determined for this day and night variation in the catch, it would be necessary to limit sampling to either the day or night. This would lengthen the time necessary to sample the area to a point where anything approximating a synoptic picture of distribution would not be obtained.

One possible way to circumvent this problem and to insure a more rapid and hence synoptic coverage of the area would be to incorporate commercial vessels into the sampling program. A number of standard size and horsepowered vessels using standard gear could be designated to fish simultaneously in unit areas throughout the Gulf. Tows would be made at set intervals, at a standard speed, and for a uniform duration. The number of days fishing required would depend on the number of vessels used, but it would be desirable to limit the sampling time to a period of not more than 4 or 5 days. Such data would provide a truly synoptic picture of the distribution of fish, furnish information on the day and night variations in the catch within specific areas, and the data could be analyzed on a basis of day and/or night tows. The implementation of such a program might prove complicated, but such a plan has definite merit and its possibilities warrant investigation.

To date, fishery hydrography has been spared for the most part the heavy pressure that has long beset meterology for predictions. Whether we like to be involved in practical matters or not, it should be kept in mind that not only do we have an obligation to make predictions for the fishermen concerning such things as year class strength fluctuations and the times and places where fish will concentrate, but what is more important, that the proof of our understanding of what is happening in the sea is to be able to specify what will happen next. We are not now able to make such preductions for although the literature dealing with the fishes of the Gulf of Maine dates to the 17th century and a prodigious amount of information as to the local distribution and abundance of the various species has been collected, there is still a great deal we do not know concerning the biology and ecology of the most abundant and commercially important species. Detailed knowledge of the life history, spawning locations and times, migratory patterns, and feeding habits is available for only a few species. In the case of haddock, for example, which species has probably been studied more than any other in the Gulf of Maine, there are still serious gaps in our knowledge concerning the various stocks in the area and their seasonal shifts in abundance and distribution, and concerning certain phases of their early life history and ecology. Census surveys, large scale taggings, and time-series hydrographic data should help fill in many of the flaws in our knowledge, but in addition, there are many problems requiring special duty.

To give an example, although we have a fair knowledge of the time and location of spawning of haddock, little is known concerning the vertical distribution of larvae and juveniles, the duration of pelagic life, and the biological and physical factors which control same. Even less is known concerning the early life history of other species in the area. But before we can hope to obtain a reliable sample of larval and juvenile fish, let alone understand the causes of their fluctuations in abundance and distribution, we need to know more concerning the pelagic phase of the life history and this knowledge can only be obtained on research vessel cruises especially designed for this purpose.

The present situation in fishery hydrography and some of the basic problems that must be solved before we can hope to understand the goings and comings of the various fish populations in the Gulf of Maine can be summarized as follows:

(1) Although we have a fair knowledge of the general details of the distribution, relative abundance, and life history of most fish species endemic to the Gulf of Maine, current survey methods and the landings of the commercial fleet are not adequate to establish the details of the seasonal and yearly variations in abundance and distribution of the area as a whole or in any of its subdivisions. We need to know more concerning all phases of the life history, on the behavior patterns, and on the routes and seasons of migrations for the species of commercial value as well as for other species of fish.

(2) For the most part, past studies of the fish populations in the Gulf of Maine have been species oriented. We need to know more concerning the inter-species relations and concerning the distribution and abundance of species which are the prey, the predators, and the competitors of the most valuable commercial species.

(3) As in the case of physical and biological oceanography, there is a basic need for synoptic data on the abundance and distribution of all species of groundfish throughout the area at various seasons over a considerable span of years. It is suggested that the most feasible method of accumulating such data would be to incorporate commercial trawlers into the sampling program. If such a multi-ship sampling program proved possible more research vessel time would be available to study specific problems.

(4) Although sampling is the heart of so much of fishery hydrography, surveys in the past for the most part ignored the fact that the populations of fish are not static and have generally been conducted by

sampling systematically or at random with the most readily available or easily handled gear according to the known or hypothetical habits of the species of fish sought, the guiding idea being to obtain a representative sample by which to estimate the size of the population at a given time. Recent studies of sampling have shown that many of the standard methods used in the past are inadequate, for fish like many other marine organisms are not distributed randomly especially during their early pelagic life. Their vertical and horizontal distribution vary with the stage of development, season of the year and time of day and many species are able to avoid slow moving collecting gear. Special studies on the nature of the distribution of the various species of fish and food organisms should be undertaken to improve the basis for designing collecting gear and sampling programs.

(5) One of the major causes of the year-to-year fluctuations in the abundance of fish appears to be the variations in survival rate during the early pelagic stages of life. Considerable effort has been devoted to elucidate the causes of these variations by correlating survival rates with variations in physical and biological conditions in successive years. To date this approach has not been very fruitful for a number of reasons. Foremost among them are the serious gaps in fundamental knowledge about the physiology of young fish and the environmental factors essential to their survival, the lack of in situ, and time series physical and biological data, and the lack of accurate estimates of the abundance and distribution of larval and juvenile fish.

(6) An attempt should be made to evaluate the general features of productivity in the Gulf of Maine and its relation to the distribution

and abundance of fish for although the literature is full of accounts of plankton or fish, very few serious attempts have been made to obtain a picture of the food chain as a whole in some one area.

(7) The most important goal of fisheries research is to prepare predictions of value to the industry. One of the most effective means of increasing fishing efficiency would be to devise methods of predicting the years when fish will be abundant (size of stock) and the areas where fish will concentrate (availability). To accomplish this goal it is necessary first to increase our understanding of the environment as well as the biology of the fish, but an effort should be made in this direction.

IV. Bottom Sediments and Fauna

Considerably less has been published concerning the bottom sediments and fauna of the Gulf of Maine than on the fishes and physical and biological oceanography, so that there is little background information to refer to. Nevertheless, the standing of our knowledge of the bottom sediments and fauna in the area is in relatively good state. The main reason for this is that the distribution and composition of sediments and the distribution, species composition and abundance of the macro and meiofauna are considerably more stable than that of other physical and biological parameters, so that data collected over a considerable period of time can be included in analyses of distribution and abundance.

The methods of sampling bottom sediments and fauna are more or less standardized and surveys of the Gulf of Maine have been made intermittently by the Bureau of Commercial Fisheries since 1955. To date, samples of sediments and fauna have been obtained over a relatively close network of stations from most areas within the Gulf. This work is continuing in order to complete the coverage of the area and to refine the coverage in regions previously surveyed. To date, the distribution of bottom sediments and the distribution and species composition of macrofauna on Georges Bank have been described (Wigley, 1961a and 1961b). The principle desideratum is not for improved methods of collection or for more data, but for greater speed in analysis of the samples. Due to the painstaking nature of this work, however, the only way in which to shorten the time required for analysis would be to increase the number of personnel involved in this work. In addition to a description and an analysis of the abundance and distribution of sediments and bottom fauna in the Gulf, future work should include a detailed photographic survey of the bottom and studies of: (1) The relation of turbulance, basic productivity, and nutrients to the bottom fauna biomass, (2) the relation of bottom currents to substrate composition and distribution, and (3) the relation of species and age distribution of fish to bottom sediment and faunal type.

Conclusions

Much emphasis has been given in this summary to the things we do not know concerning the oceanography of the Gulf of Maine and to demonstrating and discussing the inadequacies of past sampling techniques. It should be kept in mind, if it is of any consolation, that more is known of the oceanography of the Gulf of Maine than of any other area with the possible exception of the North Sea. The fact that we are able to evaluate the present state of our knowledge and to outline future programs of study demonstrate this.

It should also be noted that although a detailed study of a large number of parameters on a continuing basis in a restricted area such as the Gulf of Maine is not going to solve all the problems of coastal oceanography, such a program is of greater value than one involving more sporadic and widely-spaced observations over a larger area. Certainly much of what we learn about the oceanography of the Gulf of Maine will be applicable to other areas.

If anything, this review has demonstrated the need and value of time-series observations and continuing programs of basic research. In order to implement such continuing studies, however, some changes in current programing and in allotment of funds are necessary. This need has been brought out in two reports prepared by the National Academy of Sciences Committee on Oceanography[2/] from which the following quotations are taken.

"The importance of research freedom leads us to question the wisdom of funding individual projects one at a time rather than providing unrestricted long-term support of men or laboratories of proven ability and drive. No matter how much the funding administrator may wish otherwise, the project system imposes some serious constraints

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2/ Oceanography 1960-1970. Chapter 2. "Basic research in oceanography during the next ten years." Chapter 11. "A history of oceanography. A brief account of the development of oceanography in the United States.

on the investigator: he feels unable to abandon work when his judgement dictates, while the sudden inspiration and new line of work must often be left unexplored until it can be blown up into a full 'project'. In a sense, the support of projects is the support of work already done, for discovery and development of good problems to the point of precise definition comprises most of the scientists' working effort. To promote the sustained healthy growth of oceanography we must find ways of funding opportunities for uncommitted reflection and experiment, and programs that can be abandoned or wholely reoriented whenever the judgement of the responsible investigator dictates. Some general oceanographic support is now provided, but a great deal more of this type of funding is needed."