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Use of Marine Meteorological Observations in Fishery Research and Management

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Resource Category	Potential Increase (millions of tons) 1985	2000
Conventional species	8	14
Unconventional species (krill, squid, etc.)	5	35
Waste elimination (equivalents)	2	15
Total	15	64

Table 1. Opportunities for increased fish and shellfish production, 1985 and 2000 (Alverson, 1975)

Introduction

During the last 20 years there has been a phenomenal growth in world fisheries. Catches (marine and freshwater) rose from 27.6 million metric tons in 1954 to a peak of 70.2 million metric tons in 1971. The collapse of the Peruvian anchoveta fishery caused the subsequent decline to about 65 million metric tons in 1972. The anchoveta catch declined from a peak of 12 million to 2 million metric tons in 1973. This decline was probably caused by a combination of over-fishing and adverse environmental conditions, specifically, the occurrence of El Niño, a weather-related ocean change that visits the coast of Peru at irregular intervals.

Despite the leveling off of the total catch since 1970, there remains opportunity for significant further increases in the supply of protein from the sea. In summarizing the various possibilities, Alverson (1975) estimates that production from the ocean alone could rise from 55 million metric tons in 1973 to about 119 million by the year 2000, an increase of 64 million tons (table 1).

In a world desperately in need of protein, the possibility for increasing marine production cannot be ignored. However, this possibility will be realized only by better management of fishable stocks. Clearly, the collapse of the Peruvian anchoveta fishery points out the need for more efficient fishery management and increased research to better understand the effects of environmental changes on living marine resources.

Despite the large amount of environmental data collected over the past several years in fishery research programs, the most useful information is the marine surface meteorological observations and their historical record. There is no other marine data set that is global in nature and covers such a long period of time. These attributes are precisely what is needed in many kinds of environment-related fishery research.

Relationships established between environmental changes and fish stocks usually are empirical, and the cause-and-effect relationships may not be well understood. Thus, it is possible that the decline in a fishery is due primarily to fishing efforts too heavy for the fish stock to sustain, and the apparent relation to environmental change is only coincidental. The emerging consensus appears to be, however, that declines in many exploited fish stocks are caused by a combination of adverse environmental conditions and heavy fishing pressure. In the following examples we illustrate relationships between changes in some fisheries and environmental indices. The indices were derived from marine surface meteorological observations.

Salmon

A climatic shift occurred in the Bering Sea in the early 1970's which has had a drastic effect on the Alaska salmon fishery and significant effects on other fisheries. The 1973 and 1974 commercial salmon harvests were among the lowest since inception of the salmon fishery in the late 1800's. The low catches are attributed to the effect of the unusually cold years of 1971 and 1972 in the Bering Sea. Ocean sea surface temperatures near the Aleutian Islands in these years were the coldest for at least twenty years. In the winter of 1970-71, Aleutian land stations reported all-time low temperature readings.

The onset in the decline of sea and air temperatures appeared to coincide with an unusual southward penetration of the Arctic ice pack (Kukla and Kukla 1974). Using marine surface meteorological data, McLain and Favorite (1975) related the cold sea temperatures to large changes in North Pacific atmospheric circulation. These changes, producing northerly winds over the eastern Bering Sea, probably displaced the ice pack southward. Severe environmental stresses may have affected salmon survival in all phases of its life history, i.e., in lakes, streams, and the ocean. The severe conditions in the first two habitats appear to have been the cause of most mortality.

Atlantic Menhaden

The Atlantic menhaden at one time constituted the largest U.S. fishery. Recent studies concerning the size of yearly broods in this fishery suggest that annual variations in the surface water drift during the egg and larval stages may have been the predominant cause of variations in year-class size.

The composition of the Atlantic menhaden stock obtained yearly since 1955 shows a range in number recruited into the fishery of from 11.5 billion in 1958 to 0.9 billion in 1967. Although some variation in recruitment can be attributed to fluctuation in the size of the spawning stock, Nelson, Ingham, and Schaaf (1976) found that much of this wide range in year-class size was related to an index of surface water drift. Marine surface meteorological observations (wind and atmospheric pressure) were used to calculate an index of surface water drift, commonly called Ekman drift or transport (Bakun, 1973). Figure 1 illustrates the relationship between the magnitude of the westward or onshore drift and the year-class size. The relationship is interpreted to mean that westward surface wind drift favors drift of eggs and larvae from the ocean spawning grounds to the estuarine environment which favors menhaden survival.

Pacific Mackerel

The California fishery for Pacific mackerel is another example of environmental variation during the egg and larval stages affecting the success of the fishery. Fluctuations in year-class size were large before the demise of this fishery in the late 1960's (fig. 2). Parrish (1976) showed that most of the variation

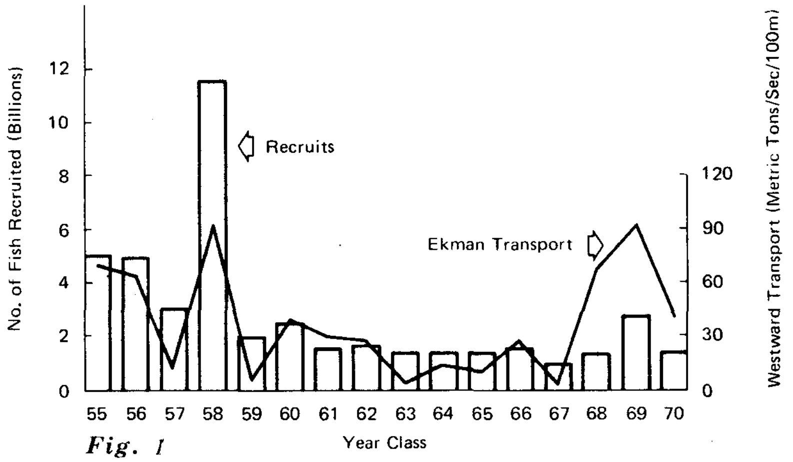


Fig. 1

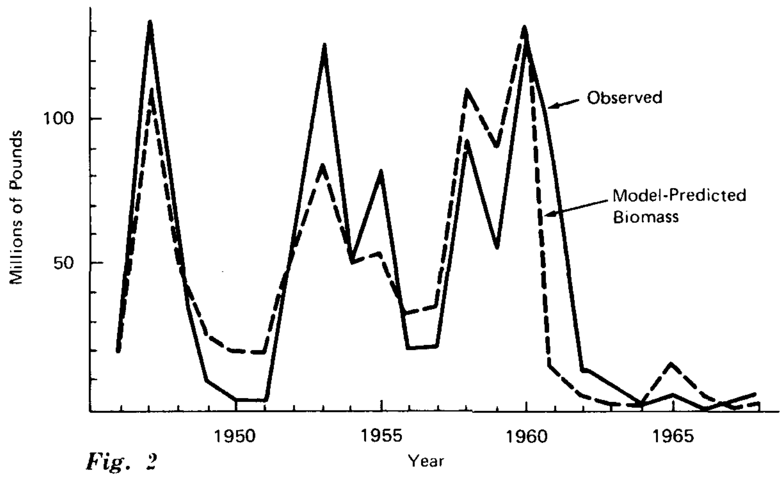


Fig. 2

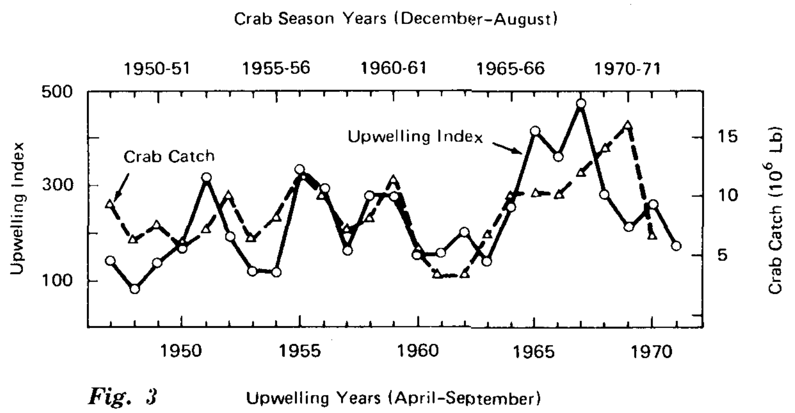


Fig. 3

Fig. 1. *Atlantic menhaden recruits at age one and east-to-west Ekman transport. (Nelson, Ingham, and Schaaf, 1976.)*

Fig. 2. *Year-class size in the California stock of Pacific mackeral. (Parrish, 1976.)*

Fig. 3. *Upwelling index values versus crab catch in Oregon. Catch lags upwelling by 1.5 years (Peterson, 1973).*

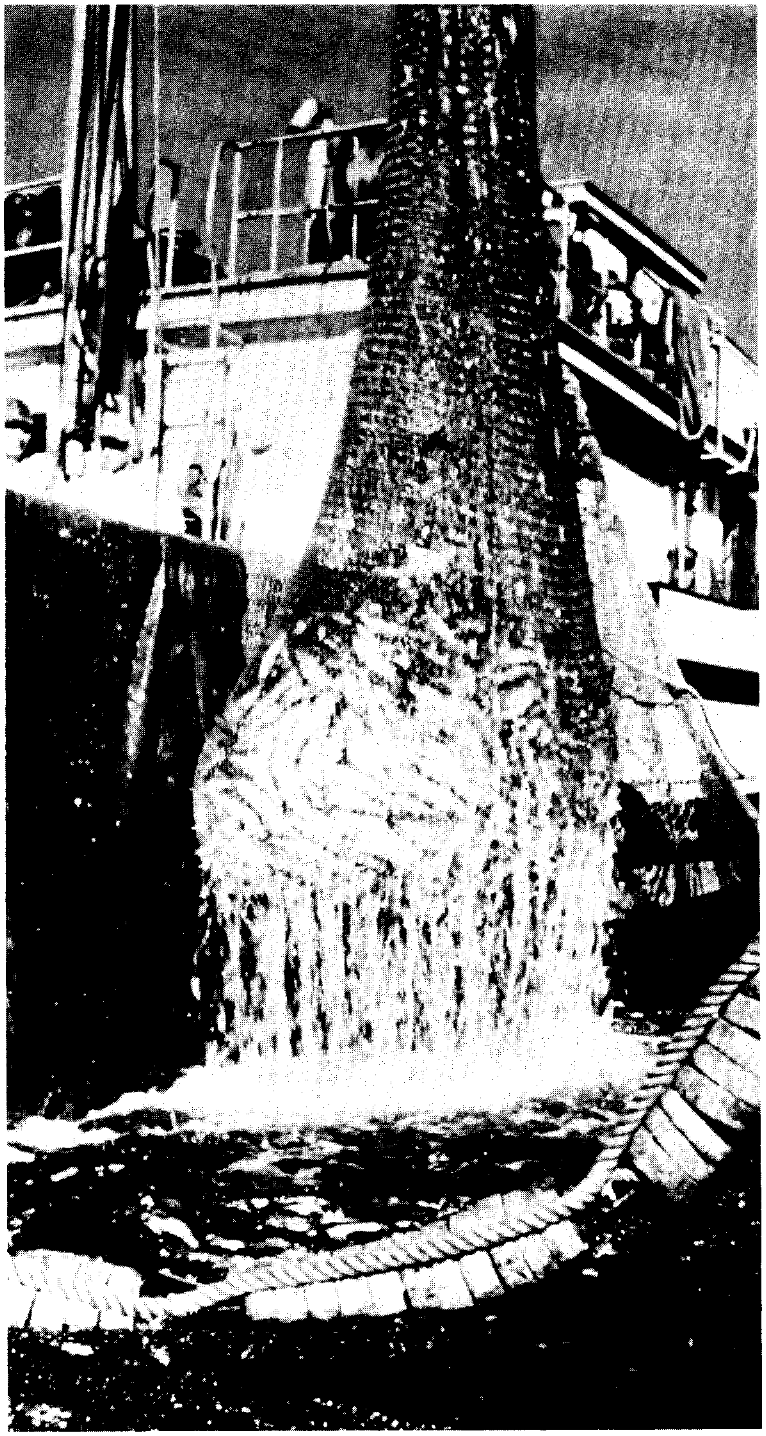
in year-class size and, thus, the size of the later fishable population, was related to fluctuations of upwelling and surface water convergence in the spawning grounds of the mackerel. In addition to the observed year-class size, figure 2 also shows the predicted year-class size in a simulation model using these environmental indices. Several years of unfavorable environmental conditions occurring during a period of increased fishing pressure caused the demise of the fishery. Population simulations suggest that the fishery would have partially recovered in the early 1970's if the effect of the environmental conditions had been recognized in time to reduce the fishing pressure before the collapse occurred. Again, indices of upwelling and surface water convergence were calculated from marine surface wind and atmospheric pressure observations (Bakun and Nelson, 1975).

Dungeness Crab

An empirical relationship between the success of the valuable crab fishery off the U.S. west coast and intensity of upwelling has been indicated by Peterson (1973) and Botsford and Wickham (1975). The upwelling index again is that calculated by Bakun (1973) from marine surface observations. The relationship for the period 1948 to 1975 is shown in figure 3, with the crab catch lagging the upwelling index by 1.5 years. The relationship is holding for recent years not shown in the figure. There was anomalously intense upwelling off Northern California in 1974, 1975, and 1976, accompanied by rising crab landings. The 1974-75 landings increased by a factor of more than four, and the 1975-76 landings increased by a factor of more than thirty over the low landings of the 1973-74 season.

Currents and Fish Distributions

Another type of environment-



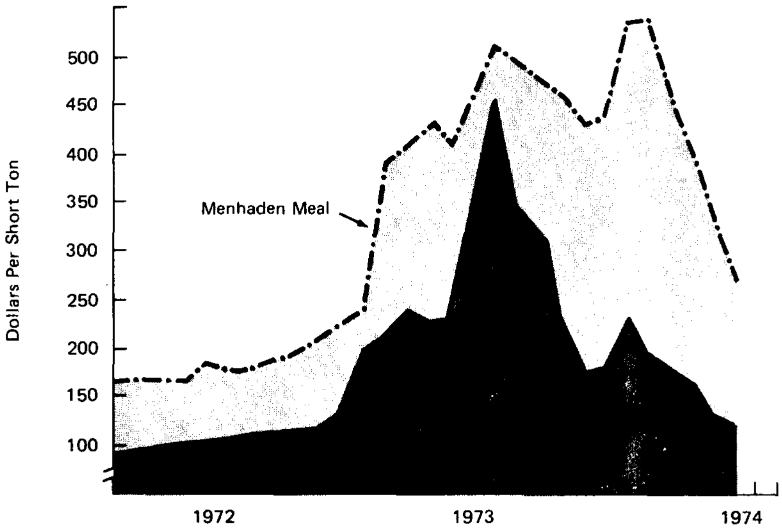


Fig. 4. Changes in monthly prices of menhaden and soybean meal.

fishery relationship concerns ocean currents. Currents can determine the migration paths of fish, as well as concentrate or disperse fish, and so affect their availability to the fisherman. For example, skipjack tuna that are found off Baja California appear one to two years later in the Hawaiian fishery. Seckel (1972) modeled the effect of baroclinic flow and surface wind drift on floating objects that had been distributed meridionally at longitude 120°W. After about two years, these objects were distributed zonally near Hawaii. Marine surface observations were used to calculate the wind-driven surface flow. The work of Meyers (1975) indicated that, in time, it may be possible to use surface observations to estimate the seasonal variability in the baroclinic flow of the Pacific North Equatorial Current. This means that the effect of currents on fish migration can be simulated by using marine surface observations.

El Niño and Air/Sea Interactions

The El Niño off the west coast of South America is a short-term climatic anomaly that has a large effect on the anchoveta fishery. This effect has been widely discussed. Here we would like to point to its tremendous impact on fish meal and soybean meal prices in the United States, which quadrupled shortly after the onset of the 1972 El Niño (fig. 4).

Differences between El Niño and non-El Niño years are reflected in large variations in sea surface temperatures not only along the South American coast in the area of the anchoveta fishery, but over vast areas of the equatorial Pacific. For example, the sea surface temperature in the eastern equatorial Pacific in November 1972, an El Niño year, was up to 5°C (10°F) warmer than in November 1973, a non-El Niño year (fig. 5). These large differences also are reflected in changes in the atmospheric circulation.

Bjerknes (1969) described anomalous conditions in the equatorial Pacific during El Niño years. He related high heat supply in the equatorial Pacific during these years with intensification of the Hadley circulation, increased flux of angular momentum, and intensified mid-latitude westerly and trade winds. He indicated that these teleconnections affect the weather over the North American continent and believed that regular monitoring of the sea surface temperature in the tropical Pacific is indispensable in long-range forecasting for North America. Namias (1972 and other studies) also stressed the importance of the oceans in long-range weather prediction.

Quinn (1972) examined air-sea interactions in the equatorial Pacific and the associated trough and ridge development over the North Pacific and the continental United States. The type of atmospheric circulation that prevails over the eastern part of the United States appears to affect the eastern seaboard shrimp fishery. Williams (1969) has shown that a good fishery tends to follow warm winters along the eastern seaboard and a poor fishery tends to follow cold winters. Johnson and McLain (1975), examining the type of circulation related to warm and cold years, have used marine surface observations to describe the anomalously warm February of 1949 and the anomalously cold February of 1958 along the eastern seaboard (fig. 6). They also identified the types of atmospheric circulation that tend to typify these extreme conditions (fig. 7).

During warm winters, as in 1949, ridge development at the 700 mb level tends to block storms of northern origin. Consequently, air masses of tropical character predominate and water temperatures are warmer. During cold winters, as in 1958, trough development over the eastern United States at the 700-mb level tends to bring cold continental air masses over the southeastern seaboard. Consequently, increased heat loss through evaporation and conduction of sensible heat results in colder water temperature. Thus it

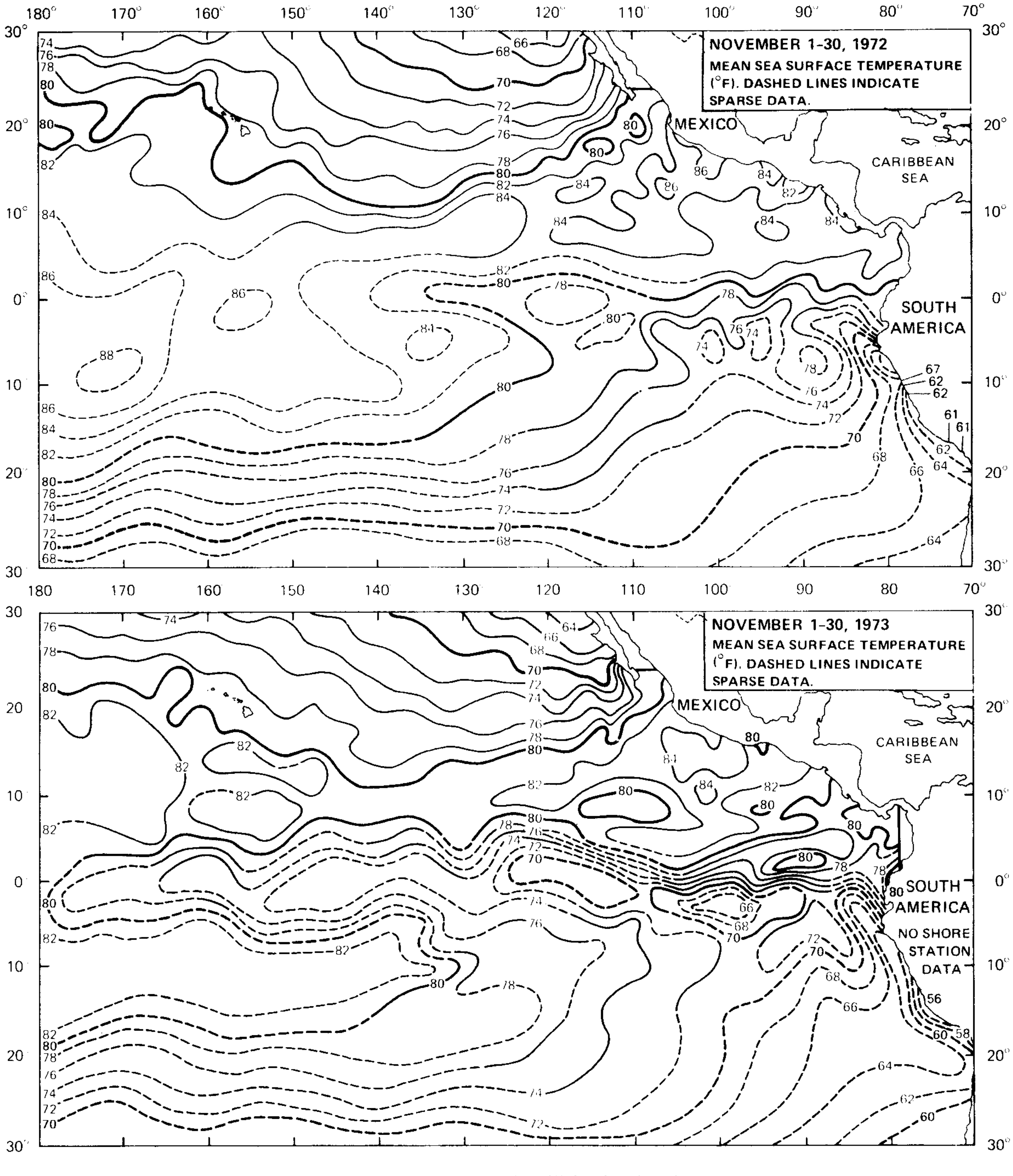


Fig. 5. Mean sea-surface temperatures, eastern tropical Pacific, November 1972 and 1973. (U.S. National Marine Fisheries Service, 1972, 1973.)

appears that ridge development in the upper air circulation is more favorable to the shrimp fishery than is development of a trough.

Conclusion

The rising demand for fishery products makes fishery management an increasingly important function. In the past, environmental considerations were not a part of management models. Our illustrations show that this omission can lead to management errors. For example, had the relationship between the Pacific mackerel and the environment been known earlier, correct management procedures could have prevented collapse of the fishery.

An important part of fishery management is prediction of year-class strength. A large year-class, for example, may lead to a large increase in fishing effort, which continues after the year-class has been harvested, leading to overcapitalization and over fishing in subsequent years of reduced stock size. A large year-class, followed by several poor year classes, is potentially disastrous to fish stocks and to the fishing industry. The prediction of environmental changes and their effect on year-class strength, therefore, is a major goal of our research.

In our examples we have tried to point out that relating changes in fisheries with variations in environmental conditions depends upon the availability of long-term marine environmental data series. The only source for such series are the historical files of marine meteorological observations.

Once a fishery-environment relation has been established, current marine meteorological observations become the basis for predictions of fish abundance. Clearly, the World Meteorological Organization's foresight in sponsoring the archival of a vast amount of marine meteorological data and in continuing a strong

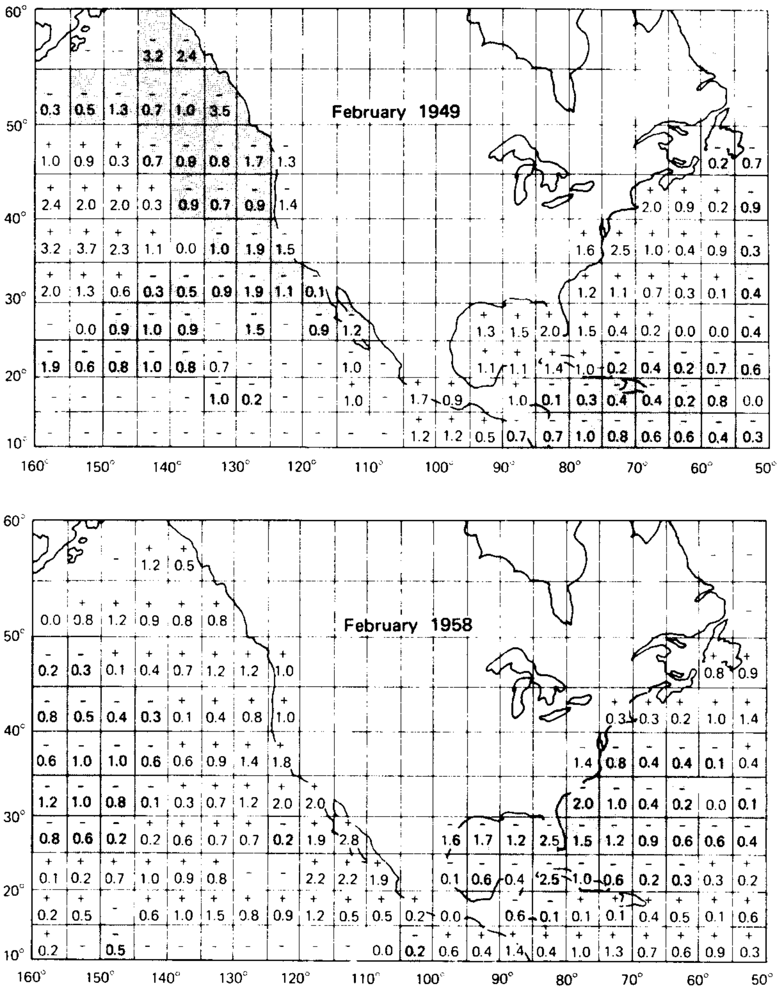
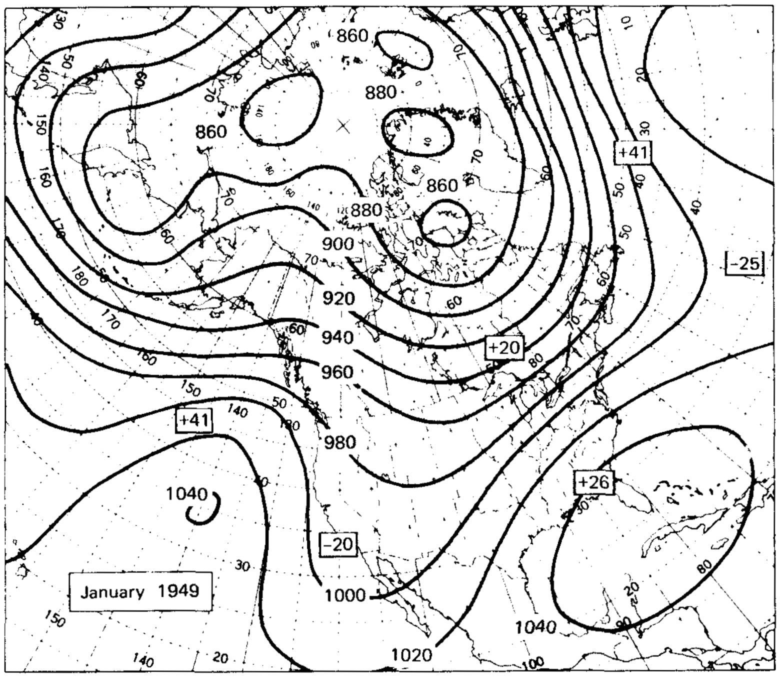
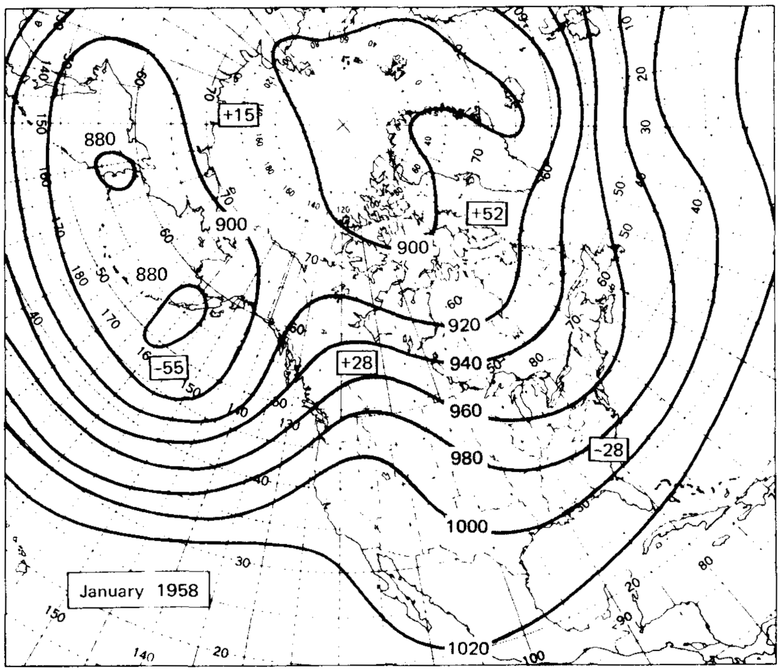


Fig. 6. (Above.) Sea-surface temperature anomalies (°C). Shaded areas are colder than the 20-yr (1948-67) mean. (Johnson and McLain, 1975.)

Fig. 7. (Opposite page.) 700-mb heights and departures from normal (in boxes) in tens of feet. (Johnson and McLain, 1975.)





marine program will have a significant impact on our ability to manage fishery resources and to help feed the hungry of the world.

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