REQUIREMENTS OF FISHERY SCIENTISTS FOR PROCESSED OCEANOGRAPHIC INFORMATION

by R. M. Laurs

According to information gathered by the Food and Agriculture Organization of the United Nations, 1970 world production of marine fish and shellfish amounted to 68.4 million metric tons. Historical records of world fish catches show that the catch has increased steadily each year for the past 30 years. For example, total world catch in millions of metric tons of marine fish and shellfish was about 16.6 in 1948, 27.0 in 1958, and 54.7 in 1968 (Figure 1).

In recent years a number of estimates have been made of how much food the ocean can produce on a sustained basis (Finn, 1961; Graham and Edwards, 1962; Meseck, 1962; Pike and Spilhaus, 1962; Schaefer, 1965 and others). These estimates have been based on extrapolation from recent trends in catch or fishing patterns and calculations based on food chain dynamics. Those based on extrapolation from recent trends in catch appear to give estimates much below those of the latter; however, the processes governing ocean productivity are imperfectly understood and much further study is needed to refine estimates now being made. Nevertheless, the present consensus among fishery scientists is that the production from the sea can be increased significantly, perhaps by a factor of 3 to 5 times that now being produced (Johnson, 1971). It is expected that the greatest increases in catch will come largely from the pelagic plankton-eating fishes (Crutchfield, 1967).

The ultimate amount of food that is harvested from the world oceans on a sustained basis will depend on 1) proper systematic scientific management of the world fishing resources, and 2) improved fishery technology, notably an increase in efficiency of fishing operations through improvement of present methods and development of new and economical harvesting techniques.

For proper scientific management of ocean fisheries it will be necessary to determine the optimum harvest, the traditional criterion of which is maximum sustained yield, for each fishery. This requires an understanding of the interrelationships among 1) population size, 2) fishing intensity, and 3) the environment. Fluctuations in the catch of a population depend on 1) the abundance of the population, 2) its availability to capture, and 3) the amount of fishing. There are means to measure changes in the amount of fishing effort and account for its effects on indices of apparent abundance (Gulland, 1964). However, variations in true abundance and availability (Marr, 1951) are difficult to identify, measure, and understand.

Fish populations are affected by artificial causes, i.e., overfishing, water pollution, etc. However, the primary cause for changes in the availability, and in most cases for abundance of fish populations are from responses of populations to changes in their environment (several authors, notably Sette, 1961 and Uda, 1961).

Fisheries Oceanography

Fisheries oceanography is the study of oceanic processes affecting the abundance and availability of ocean fishes and encompasses the disciplines of oceanography, biology, and meteorology. The goal of fisheries oceanography is to forecast accurately the changes in abundance and availability of fishes based on a fundamental knowledge of the interplay of pertinent atmospheric, oceanic, and biological processes. Fishery-prediction also requires input from population dynamics studies.

The chain of events which affects and controls the marine environment begins with the atmosphere. Changes in the atmospheric pressure field cause variations in wind stress which affect the surface circulation through changes in the velocity, depth, and breadth, and a multitude of other features of ocean currents. Currents affect the distribution of organisms at all trophic levels and, along with winds, determine the nature and strength of refertilization processes of ocean surface waters. The replenishment of surface waters affects primary biological production which, in turn, affects secondary production at each trophic level up to the fishes, with varying lags in time and space. The dynamic air-sea interaction processes which influence the heat-balance of the ocean-atmosphere system also result in marked fluctuations in the marine environment which directly affect the distribution and abundance of marine fishes.

Fishery scientists and oceanographers do not have sufficient understanding of the complex interplay of atmospheric, oceanic, and biological processes as they cause fluctuations in the availability and abundance of fishes to construct quantitative models for forecasting such fluctuations. Up to now, work has been mostly descriptive in nature, but the understanding of the complex interrelationships involved has increased and the possibility of quantifying the results and applying these to fishery prediction models is closer at hand.

For the most part, fishery oceanographers have concentrated on describing the oceanic circulation, attempted to associate physical, chemical, and biological parameters of the ocean with the occurrence of fishes, and documented and interpreted changes in the distribution and abundance of the fishes in relation to changes in these parameters.

No attempt will be made in this paper to describe the efforts of fisheries oceanography or summarize the results. For this the reader is referred to the following publications: Blackburn et al., 1962; Blackburn, 1965; Johnson, 1962; Laevastu and Hela, 1970; Owen, 1968; Sette, 1955, 1956, 1960, 1961; Schaefer, 1961; and Uda, 1961.

General Considerations of Oceanographic Data Requirements by Fishery Scientists

Before detailing the requirements of fishery scientists for processed oceanographic information, there are two general points that should be considered. Oceanography has provided knowledge of average conditions in the ocean and the processes maintaining them in equilibria. However, average conditions are rarely encountered in reality and its is the variations from average ocean conditions that affect the abundance and availability of marine fishes. Much of the effort of the fishery oceanographer is directed toward ". . . studying the changing sea rather than the equilibrium ocean and in studying the biological consequences of the changes at various trophic levels" (Sette, 1961). For his studies then, the fishery oceanographer requires data in both climatological and synoptic time scales.

Secondly, while there are many oceanographic measurements that could be used in studies to understand the effects that varying environmental conditions have on the abundance and availability of fishes, many of these measurements require specialized equipment found only on oceanographic research vessels. However, observations from research vessels usually lack both the synopticity and continuity which are necessary in fisheries oceanography studies. Therefore, it is often necessary to deduce what is desired to be known from something else that is measured in the ocean over sufficiently large time and space scales on a routine basis. For example, information on variations in ocean circulation are extremely important to the fisheries oceanographer, as well as other oceanographers; but rather than having current measurements available to him, he attempts to deduce circulation patterns from variations in distribution of ocean temperature or differences in sea level.

In the sections that follow only those variables which are available, or could be available in the near future, on a routine basis, are discussed.

Sea Surface Temperature

Ocean temperature is one of the most important and universally employed oceanographic measurements in fisheries oceanography and in fish scouting operations. Temperature is significant in marine fisheries because of the direct effects it has on the biology of fishes and because it is a most useful indicator of other prevailing or changing ecological conditions in the ocean. Not only the actual temperature, but its variations in time and space, especially its horizontal and vertical gradients, are important in evaluating the direct and indirect effects that temperature has on marine fisheries. Temperature is the most easily observed variable in the marine environment, and sea surface temperature data are relatively available over large areas of the oceans historically and on a continuing basis. Consequently, much attention has centered on studies of the distribution and abundance of marine fishes in relations to sea surface temperature.

Fishes and other marine life have preferred temperature ranges, and temperature usually sets the limits of distribution of marine organisms (Moore, 1958 and others). The optimum temperature range for distribution and fishing of tuna species, as adapted from Uda (1957) by Laevastu and Rosa (1962), is given in Figure 2. Laevastu and Hela (1970) and Uda (1957) give optimum temperature ranges for several commercially important marine fishes. Sullivan (1954) summarized the findings of various workers on the effects of temperature on the movement of fish, and on the influence of temperature on the distribution of fish, and discussed the role of the receptor mechanism in the temperature response in fish.

In addition to the role that temperature plays in the distribution and availability of fishes, it also affects abundance through its influence on spawning (Ahlstrom, 1959 and many others), survival of larvae (Murphy, 1961 and many others), feeding (Komarova, 1939), and growth (Taylor, 1958 and others). Mass mortalities of fish and other marine life have also reported to have been caused by extreme variations in temperature (Galloway, 1941). Temperature also influences the migration patterns followed by fish (McGary et al., 1961).

Information on the distribution of sea surface temperature is especially important in predicting and locating good fishing areas. Highest concentrations of tuna and other pelagic fish are usually found where there are large gradients in sea surface temperature and where the optimum temperature zone is narrow (Uda, 1961 and others). By way of a specific example of this effect, Figure 3 shows a sharp jump in catch of albacore tuna associated with a horizontal gradient in sea surface temperature.

In addition to acting directly, sea surface temperature is fundamentally related to many ocean processes which play important roles in determining the distribution and abundance of marine fishes. Knowledge of the distribution of sea surface temperature over large areas is important in the detection and monitoring of ocean currents, water mass boundaries, upwelling zones, and certain air-sea interaction processes which influence the heat-balance of the ocean-atmosphere system.

Need for Additional Data Coverage

In spite of the fact that sea surface temperature measurements are probably the most ubiquitous of all measurements made in the sea, there is still need for increased coverage both in time and space. Sea surface temperature measurements, along with marine meteorological observations, are made by merchant ships, fishing vessels, research vessels, and military vessels. The observations are radioed ashore in real-time and the data are disseminated to users over special teletype circuits. While this is a good and important scheme for obtaining synoptic sea surface temperature information, the distribution of the observations is mainly along shipping lanes and therefore large ocean areas are devoid of observations. Often these areas of scarce data are important fishing grounds, such as the eastern tropical Pacific, south Pacific, Indian Ocean, south Atlantic, tropical Atlantic, and polar regions. Figure 4 shows the number and distribution of sea surface temperature observations made during a 1-week period in the eastern tropical Pacific.

Remote-sensing of sea surface temperature from orbiting satellites (McClain, 1969) and from unmanned telemetering buoys (Howard, 1964) appears to hold great promise for providing more extensive coverage of sea surface temperature measurements. However, the total potential of sea surface temperature measurements from satellites will not be realized by fisheries until sensors are developed which will give measurements in all weather conditions. This will enable ocean temperature measurements to be made from satellites in regions of upwelling and other cloud-covered areas where the world's most important fishing areas are located (Laurs, 1972). Efforts should be stepped up markedly to increase the numbers of synoptic observations of sea surface temperature and other marine variables received from ships at sea, especially fishing vessels which often operate away from main shipping routes.

Requirements for Sea Surface Temperature Information

Fishery scientists require analyses and forecasts of sea surface temperature both in climatological and synoptic scales. Monthly means, seasonal means, and annual means and anomalies for each time scale are used in studies relating large-scale environmental variations to marine fishes and to monitor trends in thermal changes in the ocean. It is desirable to have the information both as analog charts and in a digital format suitable for ADP handling. Figure 5 illustrates monthly mean charts of the distribution of sea surface temperature and anomaly pattern in the northeast Pacific.

There is also great need in marine fisheries for synoptic charts of sea surface temperature which provide information about the short-term fluctuations in ocean conditions. These charts should contain sufficient detail to show local, small-scale features in the distribution of sea surface temperature such as locations of upwelling "fronts" and other horizontal temperature gradients, surface eddies and other "patches" of warm or cool water, etc. Because of low data density and data errors, it is usually necessary to composite data over a period of several days in the preparation of quasi-synoptic charts. However, care should be taken to insure that formulation of the analysis period takes into consideration the speed and magnitude of short-term changes in the ocean in the particular area covered by the analysis.

Synoptic analyses of sea surface temperature are used by fishery scientists in fishery forecasting operations and by fishermen in locating productive fishing areas. Japan has taken the lead in providing fishermen with synoptic sea surface temperature information in the form of charts prepared by the Japan Meteorological Agency and transmitted to fishermen via radio facsimile. Recently the U.S. National Marine Fisheries Service commenced issuance of 7-day sea surface temperature charts via radio facsimile to eastern Pacific tuna fishermen (Laurs, 1971).

Thermocline Topography and Vertical Thermal structure

If temperature limits the horizontal distribution of fishes, then we might expect that it can also limit their vertical distribution. This indeed appears to be true, for variations in vertical thermal structure, notably thermocline topography, affect the distribution and availability of marine fishes (Blackburn, 1963; Dietrich et al., 1959; Laevastu and Hela, 1970; Laurs and Lynn, in preparation; Postuma, 1957 and others); however, comprehensive studies are lacking. Laevastu and Hela (1970) give a schematic example of different depth and temperature preference by different species of tuna in tropical latitudes (Figure 6).

Information on vertical thermal structure is also used by fishery oceanographers in monitoring and evaluating other ecological conditions which affect fluctuations in catches of marine fishes, i.e., nutrient replenishment processes (Brandhorst, 1958), variations in ocean circulation (Cromwell, 1958), air-sea interaction and advective processes affecting heat flux (Roden, 1959) and location of water mass and current boundaries (Roden, 1964; Saur and Stewart, 1967). Figure 7 shows how vertical thermal structure can be used to delineate the outer boundary of the California Current.

Vertical thermal structure is also extremely important in fishing strategy for some pelagic species. For example, purse seining operations for yellowfin and skipjack tunas are more successful in thin mixed layers over thermocline of sharp temperature gradients (Green, 1967). When the thermocline is shallow the tuna do not dive into colder waters below but remain in the seine, whereas when the thermocline is deep the fish can dive under the seine before pursing (Figure 8). Information on the depth of the thermocline can also be used in other fishing operations including 1) setting depth of longlines for different tuna species, 2) setting depth of drift nets for herring and salmon species, and 3) determination of the optimum depth for midwater trawling for pelagic species (Laevastu and Hela, 1970). Information on vertical thermal structure is also important to fishermen who use sonar to locate concentrations of fish because thermal structure effects sonar ranges and sound propagation.

Requirements for Vertical Thermal Information

Like the requirements for sea surface temperature, fishery scientists have need for vertical temperature information on climatological and synoptic time-scales. Information at minimum should include depth of mixed layer and thermocline, and thermocline gradient. It would also be desirable to have information on the depth of various isotherms down to approximately 200 meters depth. The vertical thermal information should be in the form of charts and in a digital format suitable for ADP handling.

Salinity

Salinity per se does not appear to have a direct bearing on the distribution and abundance of marine fishes. Studies have shown that salinities over large ranges have relatively little direct effect on the normal fertilization, development, and hatching of marine fish eggs (Holliday and Blaxter, 1960). Variations in salinity affect the osmotic regulations of fish, but marine fishes for the most part are able to make such adjustments relatively easily (Prosser and Brown, 1962).

Except in some coastal waters where land runoff may be large, salinity variations in the ocean are relatively small. Even so, these variations can be important indications of changes in conditions which play important roles in determining the distribution and abundance of fishes. For example, Seckel and Waldron (1960) related the catches of skipjack tuna in Hawaiian waters to variations in salinity near Oahu which were apparently due to variations in ocean currents. Salinity changes can also be used to delineate current boundaries (see top panel of Figure 7) and to indicate change in water masses or in their stability conditions which affect nutrient replenishment processes (Sverdrup et al., 1942).

Requirements for Salinity Information

Fishery scientists have need for monthly, seasonal, and annual mean charts, and anomalies for each period of surface salinity. With the advent of expendable salinity-temperature-depth-sensors (Danielson, 1972), it may also be possible in the future to obtain subsurface salinity data. It is desirable to have the salinity information in the form of contoured charts and in digital format suitable for ADP handling.

Solar Radiation and Extinction Coefficient

While temperature sets the distributional limits for most fishes, the distribution of fish within their optimal temperature range is generally thought to be determined by the availability of food (Blackburn, 1969 and others). Also, the availability of food is probably the ultimate factor affecting larval fish survival (Lasker, 1963; Saville, 1971) which in turn is a major factor contributing to fluctuations in catches of fishes. It is obviously apparent that information on fluctuations in the distribution and abundance of food for various species of fish would be extremely important in fisheries oceanography; it is equally apparent that such information will probably never be available. However, indices of primary production and secondary production have been developed (Parsons and LeBrasseur, 1968; Sverdrup, 1953) which may provide indirect information on potential food available. Parsons and LeBrasseur (1968) indicate that the following information reported from ships of opportunity, aircraft, etc., and summarized as a monthly mean for each 5° quadrangle would allow prediction of gross variations in primary productivity: 1) solar radiation measurements corrected for cloud cover and reflection, 2) extinction coefficient measured by disposable light meter, and 3) mixed layer depth.

Spectral measurements of ocean color may also be useful in locating areas of high biological productivity since they can be used to determine the amounts of chlorophyll in the ocean. It appears that synoptic measurements of sea surface temperature and chlorophyll deduced from spectral measurements could provide valuable information for locating potential areas of good fishing (Blackburn, 1969). Ocean color can also be used to delineate water masses and trace currents.

It appears quite probable that spectral measurements of back-scattered light from the ocean surface will be made by remote sensing in the near future to provide information on ocean color on a global basis (Clarke, et al., 1969). Fishery scientists could use weekly averages of ocean color information in the form of maps of percent composition by red, yellow, green, and blue wavelengths. The information should also be in a format compatible for ADP handling.

Meteorological Observations

There are a number of oceanographic factors that affect the distribution and abundance of fish which are directly influenced and/or determined by meteorological conditions.

No attempts will be made in this paper to discuss the relations between meteorological conditions and ocean conditions; these are well-treated in many textbooks (e.g., Sverdrup et al., 1942) and papers by Clark (1972), Namias (1960, 1963, 1969, 1970 and others) and others. Likewise, this paper will not discuss the needs of fishermen for marine weather information. The influence of weather on fishing operations is discussed by Kesteven (1953) and Terada (1968).

Meteorological data which are important in fisheries oceanography and fishing operations include most of the synoptic surface marine weather observations which are made by ships at sea: barometric pressure, cloud cover, air temperature, air-sea temperature difference, dew point, wind direction and speed, swell direction and height, and wave direction and height. An example of how meteorological data along with oceanographic and fishery data are being used to examine the interrelations between environmental conditions and the distribution of albacore tuna is shown in Figure 9.

Requirements for Meteorological Information

Fishery oceanographers need analyses of meteorological observations noted above both in climatological and synoptic time scales. It is desirable to have the information in graphical form and in a digital format suitable for ADP handling.

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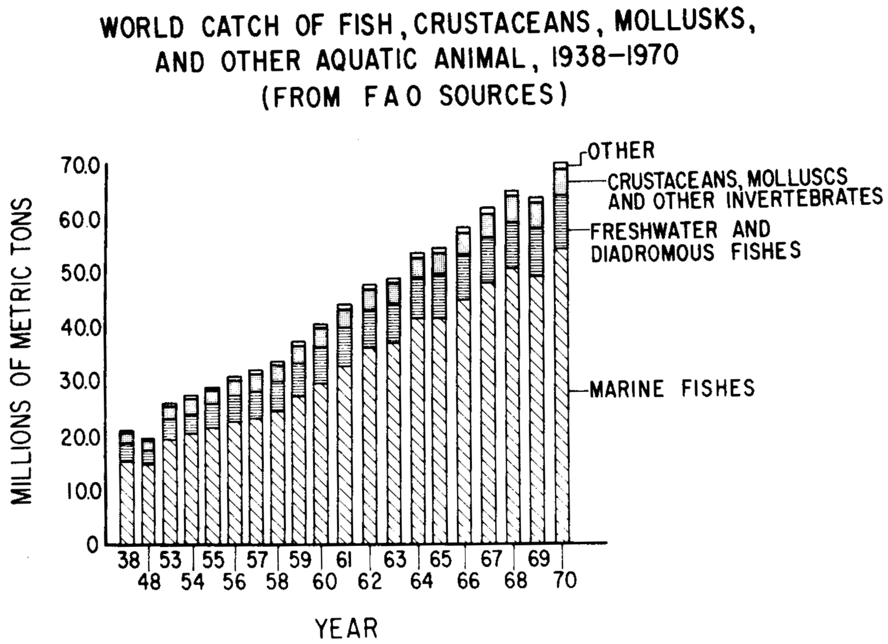

Figure 1.--World catch of fish, crustaceans, mollusks, and other aquatic animal, 1938-1970 (from FAO sources).

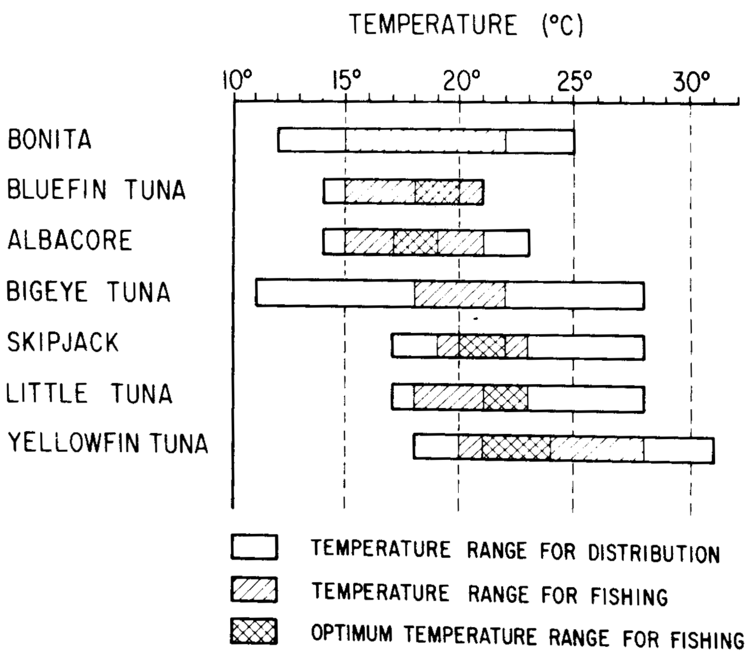

Figure 2.--Temperature range for distribution and fishing of tuna species (from Laevastu and Hela, 1970).

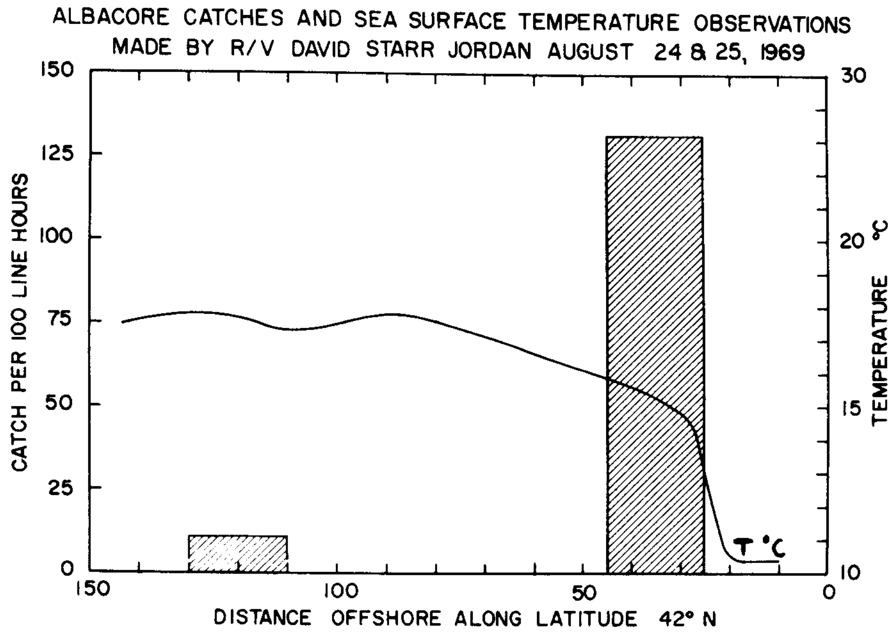

Figure 3.--Albacore tuna catches in relation to sea surface temperature.

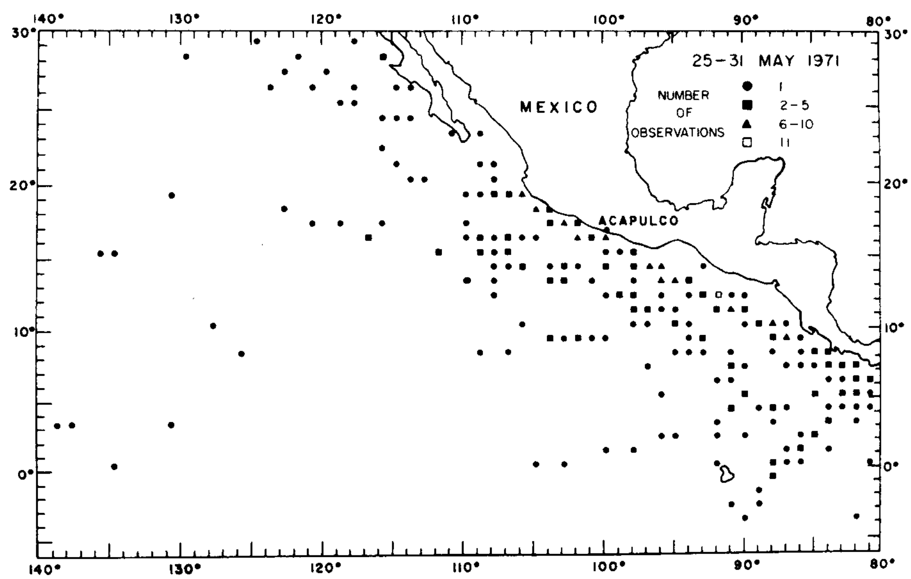

Figure 4.--Number and distribution of sea surface temperature observations made during a 1-week period in the eastern tropical Pacific.

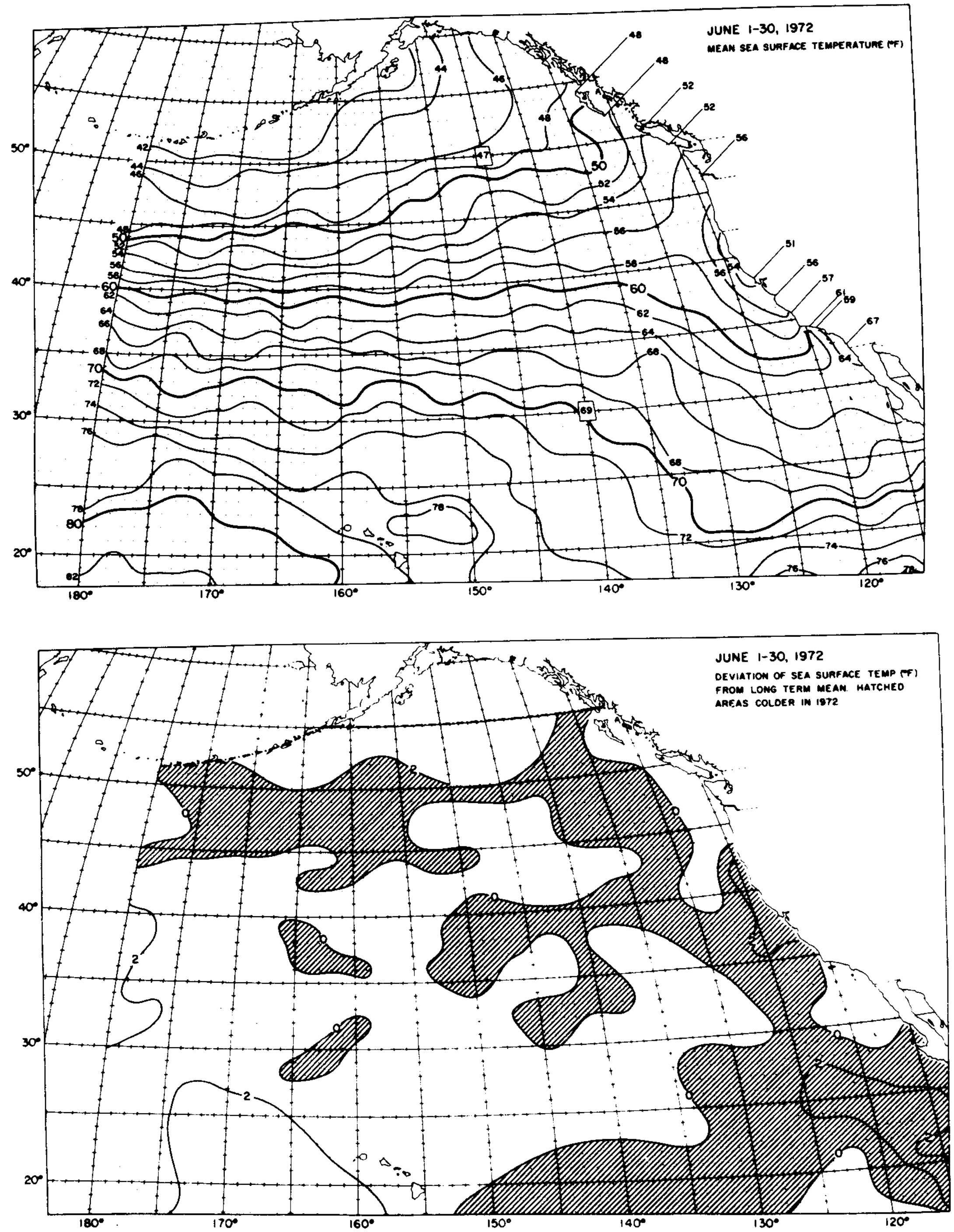

Figure 5.--Monthly mean charts of the distribution of sea surface temperature and anomaly pattern in the northeast Pacific (from National Marine Fisheries Service).

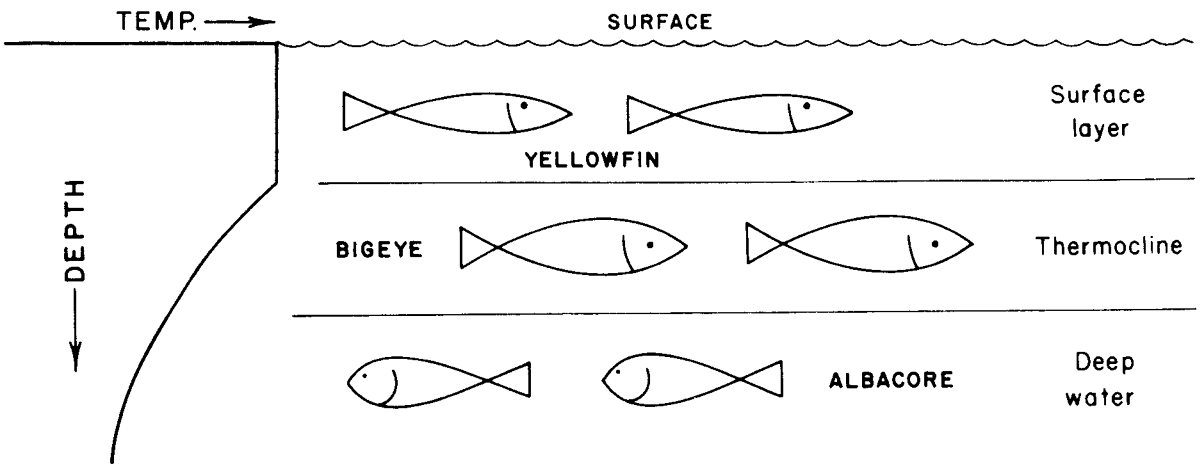

Figure 6.--Schematic example of different depth and temperature preference by different species of tuna in tropical latitudes (from Laevastu and Hela, 1970).

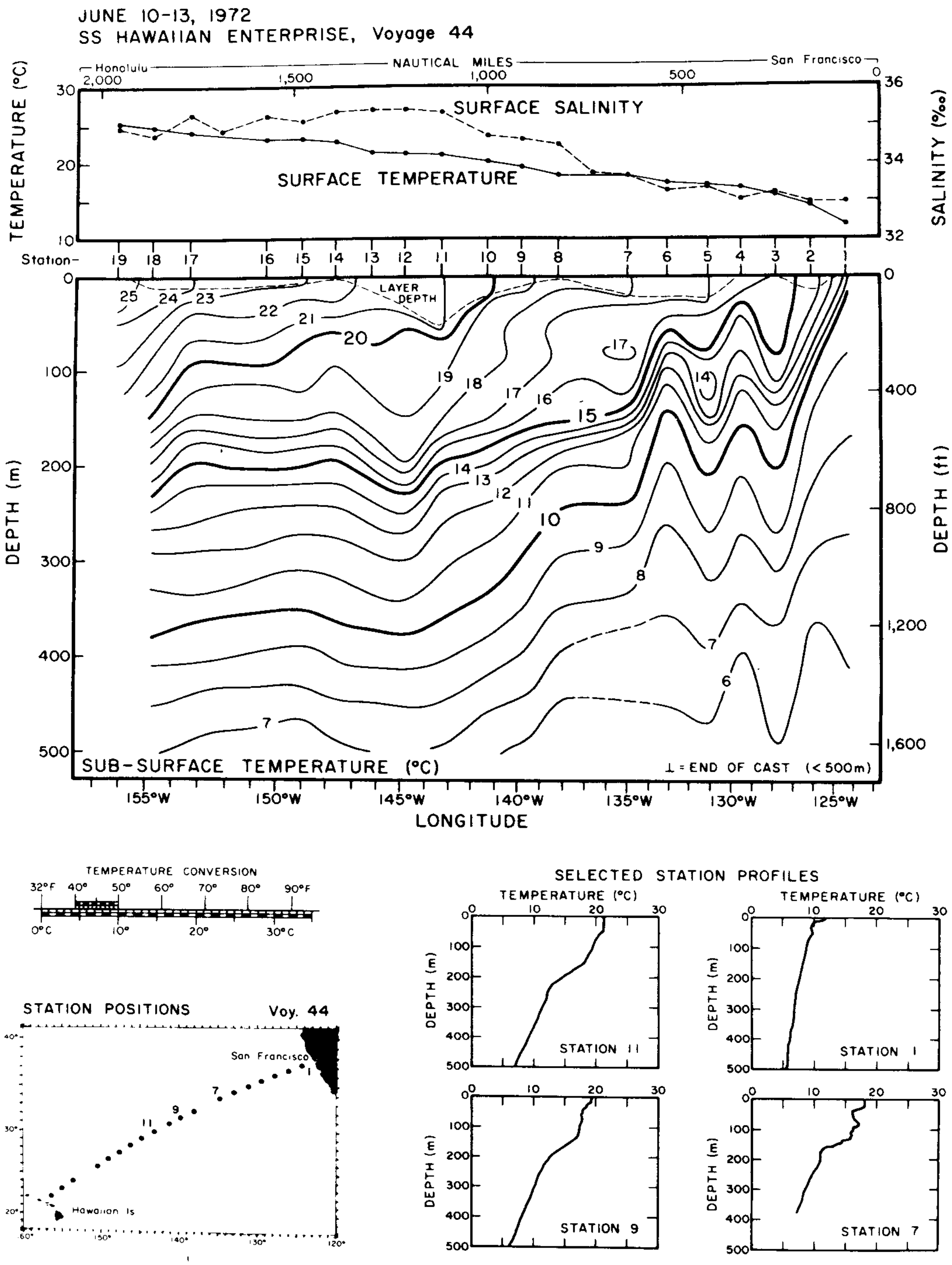

Figure 7.--Vertical thermal structure and surface temperature and salinity between San Francisco and Honolulu. Outer boundary of California current indicated by downward slope of isotherms and increase of salinity at about 135° W (from National Marine Fisheries Service).

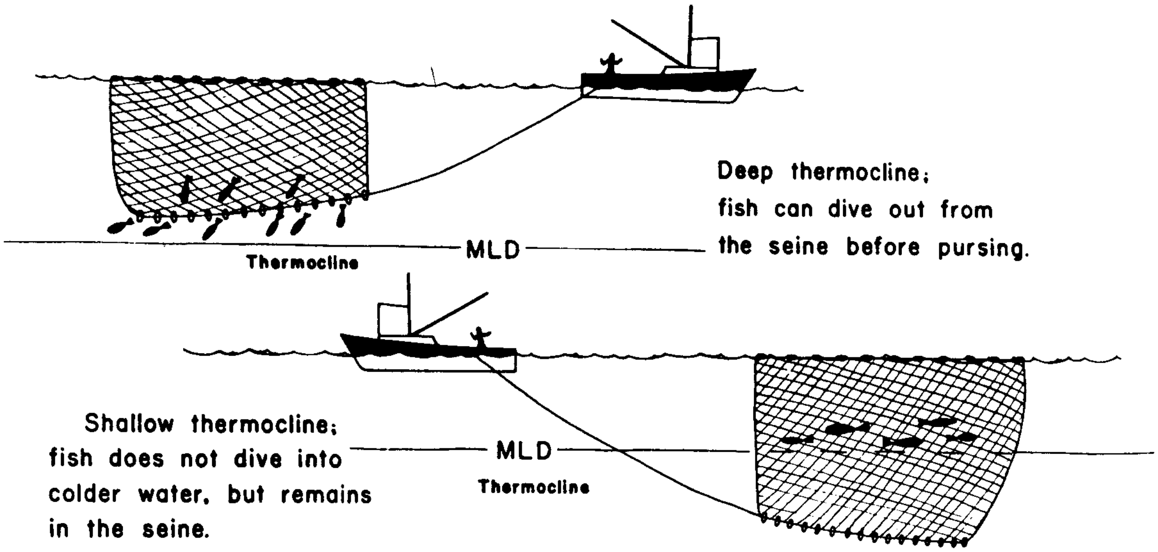

Figure 8.--Schematic example of the effect of different mixed layer depth on purse seining for pelagic fish (from Laevastu and Hela, 1970).

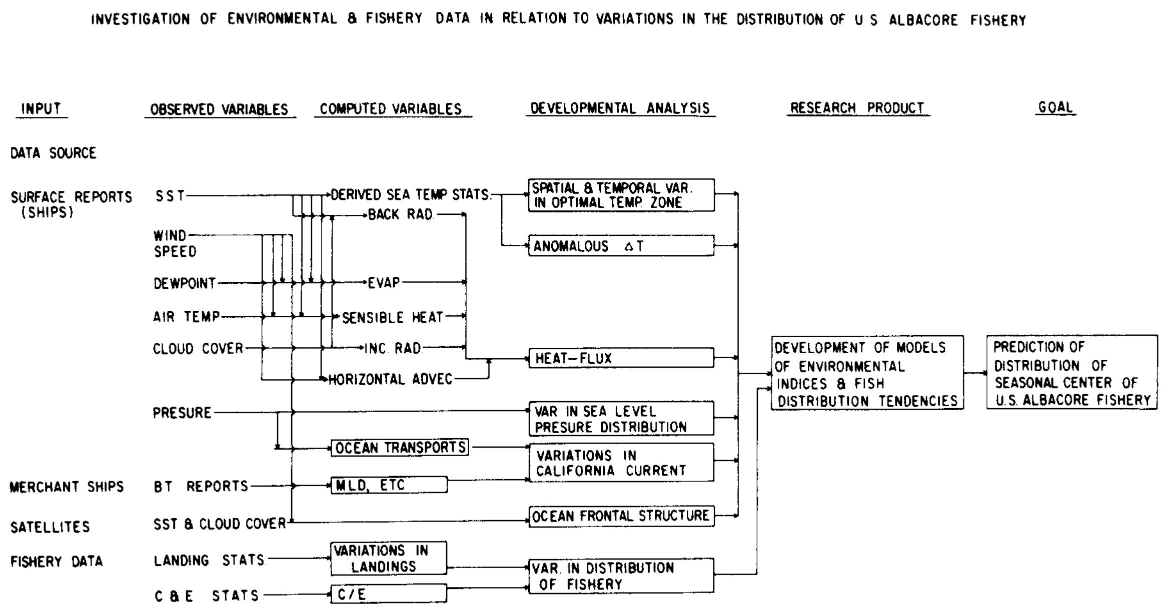

Figure 9.--Example of how meteorological, oceanographic, and fishery data are being used to examine the interrelations between environmental conditions and the distribution of albacore tuna in the northeast Pacific (from National Marine Fisheries Service).