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Satellite Remote Sensing and Fisheries Applications

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SATELLITE REMOTE SENSING
AND FISHERIES APPLICATIONS

BY

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ABSTRACT

Satellite remote sensing has the capacity to aid the three major components of a fishery: research, management, and the fishing industry. An evaluation of the potential of satellite-derived data to the fishery is based upon six case studies which are presented as evidence of the capabilities of satellite-borne sensors. Peripheral applications pertaining to the marine environment and possible applications for the future are reviewed. Three basic categories of remote sensing programs related to the fishery are defined: one to test the applicability of the technology to the field of fisheries; another to employ the technology to fisheries research; and a third to provide remote sensing technology for commercial interests. Problems limiting the usage of remote sensing in fisheries are discussed. The possibilities of initiating a commercial venture to provide sea surface temperature charts to the fishing industry are explored; the foundation for such a venture at the present would be precarious. It was determined that the most successful contributors to remote sensing of fisheries were sea surface temperature and ocean color data. Data on sea surface wind activity is expected to be of great value, although initial studies were terminated with the early failure of the SEASAT-A mission. Temperature sensors and a scatterometer are included in future space programs; an ocean color imager is not. Until a full complement of relevant sensors is in orbit, the full potential of

satellite remote sensing to the fishery cannot be realized. The factors governing deployment of an ocean color imager, and therefore limiting the potential of remote sensing, are of a political and economic nature. As a result, certain activities of import to fisheries are endangered, and many programs reliant upon ocean color data remain experimental.

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This thesis is dedicated to the memory of my mother, Carol Hollinger Turton, who worried that I too often don't finish what I begin.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Fisheries resources, if properly managed, can provide continuing benefit to mankind. Fisheries managers require up-to-date, reliable information to effect prudent management plans. Satellites acquire information over vast areas in short periods of time that is, in general, available to the public soon after it is collected. It may therefore be a source for some of the information required by fisheries managers.

The problem undertaken herein is to determine the viability of satellite-derived data as a fisheries research tool, and to evaluate the extent to which the potential, if any, has been developed. The assumptions made are that fisheries managers will continue to strive for the preservation, conservation, and sensible utilization of renewable marine resources and that satellite data will continue to be available.

For the purpose of this research marine fisheries will be defined as consisting of three components: Fisheries Research, Fisheries Management and the Fishing Industry. The three aspects of fisheries are interrelated - the interest upon which research and management are based stems from the economic contribution of the fishing industry to society. The term industry will be applied primarily to commercial fishermen who, in locating and harvesting fish, constitute the initial link in the chain which is the entire industry. Processors, distributors, support services, and consumers form the remaining links of the chain.

The net benefit of fisheries to mankind is twofold. First, fish are an important source of protein. In many developing nations fish may be the major source, and as such satisfy a fundamental need. In more technologically oriented or agriculturally advantaged countries, fish is not required for its protein and thus its direct consumption becomes a matter of choice. In these countries externalities associated with consumer preferences become important. In either case, fish is a valuable protein source, whether in response to basic nutritional needs or as a reflection of gastronomic whimsy. Second, fishing is a source of income to fishermen and to the numerous employees of the industry in its many forms.

Fish have been a source of protein for millenia. The resource is renewable, and it is of the utmost importance to maintain that renewable status. As technology evolves and is applied to finding fish, it facilitates the harvest of fish. In the interest of preserving the resource, management promotes the greatest possible harvest without permanently endangering the standing crop. An entire science is dedicated to determining the state of the fishery, predicting its maximum yield and ensuring that the fishery remains to renew itself. Without fisheries management, a primary nutritional source might be seriously threatened.

Fisheries management is the pivotal element uniting the three components of a fishery. Management's primary function is to receive information pertaining to stock well-being, and determine how the fishery can best be utilized. Management decisions which were once based entirely upon natural factors are now tempered by political considerations. As territorial jurisdiction is extended throughout the world's oceans, resource ownership and allocation become of primary importance.

Remote sensing is defined as the acquisition of data or derivative information about objects or phenomena with a recording device not in physical contact with the object or phenomena (Cornillon, 1982). It should be noted that by adhering to the strictest definition of satellite remote sensing, data is limited to that from signals originating at or reflected by the Earth's surface. Thus the use of electronic tracking and communication devices, though mentioned briefly in subsequent chapters, is generally excluded from this study. Satellite remote sensing is a highly developed technology that can provide significant information pertaining to the oceans' environment and living resources. This information may be direct or derived. Satellite remote sensing was initially used to study meteorology and measure terrestrial resources. As the technology became more sophisticated and scientists sought new applications, the range was extended to include the oceans.

The purpose of this research is to determine the contribution satellite remote sensing can make to the three constituents of fisheries. Six case studies that represent past applications of satellite remote sensing to fisheries are reviewed. Less direct applications which provide relevant environmental information and proposed applications for the future are then considered. A discussion evaluates these applications and addresses the problems inherent in developing operational remote sensing programs as well as the future of oceanographic remote sensing. Concluding remarks follow. A brief overview of pertinent satellite and sensor technology is provided in Appendix I.

Goals and Needs of the Fishery

It is the responsibility of fishery biologists to provide stock assessments and yield models for the management community. Biologists also formulate predictive models designed to gauge fishery stock responses to various environmental conditions and management plans. In order to fulfill these duties, biologists must have information on the biology of fish, the environment and how it affects the fish, and certain aspects of the fishing industry (i.e., fishing pressure and harvest methods).

Fishery managers must then assimilate these assessments and models to devise a management strategy that is timely and prudent and will benefit mankind and resource alike. Basic requirements for fishery management include an institutional framework within which to function, a methodology for synthesizing information, and the authority to implement and enforce management. Management techniques should be of a nature which can be reasonably borne by the fishing community. The information from biologists provides a foundation for all management and is supplemented by fishery statistics and determination of fishing pressure (including catch per effort and gear effectiveness data). In the United States this input is then modified by socio-economic considerations of the impact of management on the fishing community, as dictated by law in the Magnuson Fisheries Conservation and Management Act (MFCMA) (U.S. Public Law, 1976).

Clearly, fish are the fundamental need of fishermen. Fish must be located and harvested efficiently and sold for maximum profit. The greater the ease with which the fishermen capture and market their prey, the more efficient and less costly their operations are. As fishermen are encouraged to work within the guidelines of management policies, the regulations to which they must adhere should not diminish fishing efficiency. Fishermen also need timely information on weather conditions. If ice, wind and high seas can be accurately detected, the safety of crew and gear can be better assured. These factors unite to enable fisherman to provide protein to the community and a livelihood for themselves.

CHAPTER II

SIX CASE STUDIES

Introduction

This chapter reviews six case studies carefully selected to illustrate applications of satellite-derived data to the various, sometimes overlapping, components of fisheries. Numerous cases were considered; these six span over a decade of research (1972-1983) and reflect initial attempts to formulate and refine methodologies. There is geographic as well as species diversity. Six sensors were employed to obtain information on a variety of parameters. Objectives of the studies ranged from predicting the location of tuna and menhaden to developing models to measure biomass, larval transport and primary productivity.

These cases, though of an experimental nature, were successful in detailing positive contributions the interpretation of satellite data makes when applied to fisheries problems. Each case will be briefly outlined and discussed. In the next chapter the discussion will be expanded to include other studies which may not immediately derive fisheries information, but which nonetheless bear heavily on the marine environment.

Gulf of Mexico Menhaden Study

In 1972 the National Marine Fisheries Service (NMFS) began a fishery investigation in the Gulf of Mexico in conjunction with the National Aeronautics and Space Administration (NASA), the National Fish Meal and Oil Association (NFMOA), and various supporting organizations including the local fishing industry. The primary objective of the investigation was to determine the feasibility of using remotely sensed data to enhance management and utilization of coastal pelagic resources (Vanselous, 1977).

Gulf menhaden (brevoortia patronus) was chosen as the target species because the fishery is well-developed (largest volume fishery in the US), the industry was cooperative, and there exists a large body of knowledge on the biology of Gulf menhaden. In addition, menhaden are surface schooling fish, and are thereby affected by the environment at the ocean's surface which can be most effectively measured by remote sensing techniques (Vanselous et al., 1975). The area chosen was an active fishing ground, a representative menhaden habitat, covered by LANDSAT, and logistically favorable. The experiment was designed to collect data from remote sensors, convert it into oceanographic data, correlate the data with menhaden abundance and distribution, and determine if the relationships had applications for commercial fishing operations and resource managers (Vanselous, 1977).

Oceanographic information was gathered from the Mississippi Sound (an area 1 x 110 km) by sensors mounted on the ERTS-1 satellite and on high- and low-altitude aircraft, and by extensive sampling from oceanographic and fishing vessels. Three satellite images were obtained; only that of August 7, 1972 was sufficiently free of cloud cover to be of any use. These data were then used to identify the oceanographic preferences of menhaden. Parameters measured included sea surface temperature, salinity, turbidity (Secchi disc visibility depth), color (Forel-Ule color scale), surface chlorophyll content and water depth. Secchi disc visibility, Forel Ule color measurements, and salinity were consistent in the capture areas, suggesting a relationship between these parameters and menhaden distribution (Kemmerer, 1980). All fish schools lie within or immediately adjacent to the low-density areas. A model was constructed to predict areas of high, moderate and low menhaden distribution. All the parameters in the model, except water depth, can be measured remotely, indicating that remote sensing can be a tool in locating menhaden distributions.

A second (1975-1977) study utilizing LANDSAT data to predict and verify high probability areas of menhaden location was designed as a logical extension of the ERTS-1 Menhaden study. In 1975 the same Mississippi Sound area and a 5,200 km square rectangle off Atchafalaya Bay, Louisiana were sampled. In 1976 the study area was a 185 km Louisiana coastal region, adjacent to the 1975 area (Fig. 1). The primary goal was to verify and refine the relationship between environmental parameters and the availability and distribution of menhaden (Vanselous et al., 1978). The assumption was made by the researchers that if menhaden are consistently caught in waters similar with respect to one or more oceanographic parameters, then those parameters relate to the distribution of the fish. The investigation was designed first to determine the environmental preferences of menhaden and then to correlate those preferences with remotely sensed data. Radiance measurement data from test areas with and without observed menhaden were used to construct a statistical algorithm for each spectral band. The LANDSAT image was then classified into high- and low-probability areas for the location of menhaden (Fig. 2). In 1975 most of the positively identified fish schools were located either within or immediately adjacent to the high probability areas. These results indicated to researchers that classification accuracies between 80 and 90 per cent could be expected with LANDSAT MultiSpectral Scanner (MSS) data. In 1976 an additional objective was to illustrate the utility of a satellite-aided fishing operation. The industry was provided with near real-time information on high probability areas and fishing vessels were used to verify fish locations in these areas. Again, most of the menhaden were located within or immediately adjacent to designated high-probability areas (Kemmerer, 1979).

The investigators coordinated a large research effort mobilizing government agencies and industry and proving that satellites can provide fisheries significant information on a geographic scale far surpassing that available with traditional shipboard methods. Intensive sea surface sampling was required to calibrate sensors and algorithms were developed to translate raw satellite data into working form. Two major problems were encountered; cloud cover interfered with satellite images and delays in receiving data diminished the real-time nature of that data. Both problems could be somewhat mitigated in an operational system. Increased satellite coverage would make each pass less essential, as there would be others within a short time. Receiving stations or instantaneous data transmittal from another source would provide researchers with data on a more immediate basis. The study proved the viability of remote sensing as a research tool by elucidating the relationships between the surface environment and the fishery.

Brazilian Shrimp Study

This was a preliminary study undertaken in 1972 by the National Marine Fisheries Service in accordance with a United States-Brazil agreement to determine the species distribution of shrimp available to the commercial fishery (Vanselous, 1977). Extensive biological resource surveys were conducted in June and July of 1972. These data were augmented by log books maintained by the shrimp fleet. In conjunction with this study remote sensing images from the ERTS-1 (LANDSAT) satellite were used to delineate the relationships between the distribution of shrimp stocks and coastal turbidity patterns.

The shrimp fishery off the coasts of Guyana, Surinam and French Guiana is composed of four species of shrimp: pink-spotted (*Penaeus brasiliensis*), brown (*Penaeus astecus subtilis*), pink (*Penaeus duorarum notialis*), and white (*Penaeus schmitti*). Each species has a distinct distribution pattern (Fig. 3). The grounds were classified as areas of primary and secondary turbidity where stratification parallels the species distribution in orientation and shape (Cummins and Jones, 1973).

Theoretical classifications of solar penetration into ocean water suggest that depths of up to 0.5, 3 and 15 meters can be penetrated by MSS bands 6,5, and 4 respectively. In this case vertical stratification within turbid zones was deduced by comparing penetration of one MSS band to that of another. If a turbidity feature was apparent in the image derived from one band, but not in the image of the next highest band it was considered to be deeper than the penetration capable in the higher band. This provided the researchers with information on the integrated turbidity with depth; for sub-surface turbidity patterns the new information is conclusive. Because stock distibutions could be measured and located and the species' turbidity zones could be identified from satellite-generated data there is the potential to apply satellite imagery to determine the relationships between species distibution and turbidity patterns (Brucks et al., 1975).

This study, although preliminary in nature, is of particular interest because of the sub-surface information provided by manipulation of satellite-derived data. Sea truth confirmation of the stratified turbidity levels and the correlation of these levels with the distribution of the four species of shrimp indicate that under certain circumstances information derived from satellites is not restricted solely to the surface of the ocean, thus extending the scope of remote sensing as a research tool.

SEASAT-A Surface Layer Transport Study

This fishery oceanographic investigation was planned by the National Marine Fisheries Service to establish the relationship between surface layer transport and year class recruitment of estuary-dependent shellfish and finfish. In support of this investigation, the National Fisheries Engineering Laboratory designed a four-year study to measure wind stress and estimate surface layer transport, using SEASAT-A scatterometer (SASS) data (Brucks and Leming, 1977). Unfortunately, the SEASAT mission was prematurely aborted, hence insufficient data existed to complete the objectives of the study. However, the concept of the study is an important one and is included here as an example of the potential of remote sensing when applied to fishery problems.

Ninety per cent of the catch in the Gulf of Mexico is composed of shrimp, menhaden and ground fish. These species are spawned in offshore waters and transported by surface currents to nursery grounds in estuaries (Brucks and Leming, 1977). Without proper currents, eggs and larvae will not reach the estuaries, will not mature, and the year class will be severely and adversely affected. The investigators had hoped to conduct a three phase study that would eventually provide them with an operational system enabling them to monitor, model and forecast surface layer transport mechanisms for these important fisheries. The initial phase, which was completed in 1977, was a field study off the coast of Southern California (Brucks et al., 1980). Radar scatterometer instrumentation and methodologies were developed that resulted in modeling techniques for the correlation of surface stress at the air/sea interface, with backscatter signatures of surface roughness measured by a radar scatterometer. The second phase was to be a field test in the western Gulf of Mexico that would ascertain and describe large-scale ocean dynamics. The third step would have established the operational system to provide the data for models for forecasting and stock assessment (Brucks and Leming, 1977).

In the context of egg and larval transport a system capable of monitoring and predicting surface layer transport would be of great value. It would enable scientists to determine, well in advance of the fishing season, the condition of a particular year class. Armed with pre-season forecasts, managers could then implement management strategies designed specifically to exploit a healthy year class or to protect a weak one. This would be instrumental in stabilizing the nature of the fishery. Over-fishing and underexploitation would be minimized, and long-range planning could be conducted with some degree of certainty by both management and industry.

California Anchovy Study

During the period from 1980 to 1982, the California Cooperative Oceanic Fisheries Investigation conducted intensive anchovy (*Engraulis mordax*) egg surveys in the Southern California Bight. The primary objective of this study was to estimate anchovy biomass for optimum yield calculation in accordance with the Northern Anchovy

Fishery Management Plan. The National Marine Fisheries Service, working with the Scripps Institution of Oceanography Remote Sensing Laboratory, used Advanced Very High Resolution Radiometer (AVHRR) temperature data and Coastal Zone Color Scanner (CZCS) phytoplankton pigment data to identify oceanic processes that play an important role in the survival of fish eggs and larvae and to determine relationships between sea surface temperature variations and distributions of anchovy spawning (Lasker et al., 1981).

In March and April 1980, thermal imagery from the AVHRR was taken coincidently with extensive shipboard sampling of anchovy adults and eggs. The thermal image from April 6 was superimposed with the plot of the geographic distibution of anchovy catch (Fig. 4) (Fiedler, 1983). At this time there were two distinct temperature regimes in the area in which anchovy spawning occurs. There was cold water resulting from upwelling at Pt. Conception and north moving southward, and a large body of warm water extending north from Baja California (Fig. 5). The distribution plot indicated that spawning was confined to the Southern California Bight with the cold water ($\leq 14^{\circ}C$) as the seaward boundary. The image/distribution plot findings were corroborated by mapping first day egg distribution on a map of shipboard-derived sea surface temperature observations. It was determined that the modal temperature for spawning was 15-17°C, higher than the years 1969-1979 during which the modal spawning temperature was 14-15°C (Fiedler, 1983).

In 1980, determination of the age of anchovy eggs provided information on the drift of the eggs and the integrity of the water masses. The eggs stayed with the body of water in which they were spawned. Satellite images showed minimimal advective mixing, thereby suggesting that the warm water containing the eggs is not subjected to variations in temperature (Lasker et al., 1981). Extensive ground truth was provided by the Research Vessel David Starr Jordan, and confirmed that the AVHRR data were accurate to 0.5^{o}C.

An unusual oceanographic feature was visible in the thermal image. The Channel Islands, and Santa Catalina and San Clemente islands appear to influence the circulation in the Bight (Fig. 5) (Lasker et al., 1981). The cold water mass moving southward from Pt. Conception encounters these islands and moves around them. The islands shield the inshore areas, and a warm water "wake" is created. The wake of Santa Catalina extended up to 225 km. This feature was observed in the thermal image, and later confirmed by shipboard temperature observations on a transect across the wake.

Similar egg studies were conducted in 1981 and 1982. AVHRR data was supplemented by phytoplankton pigment data obtained with the Coastal Zone Color Scanner. Although researchers found temperature and phytoplankton concentration described the areal extent of spawning location, some of the areas that met the environmental criteria hosted no spawning activity, leading to speculation that other factors may influence spawning incidence, perhaps salinity and/or water stratification (Fiedler, 1983).

The researchers concurred that the synoptic nature of the satellite data greatly benefited the interpretation of spatial distributions from fish surveys and the description of important ocean processes. Lasker et al. (1981) conclude: "With sensors for wind, chlorophyll, and wave height, a suite of information may make it possible to use ships more effectively for the study of fish egg and larval distibution and mortality, particularly by judicious deployment of ships guided daily by satellite information. Such information is vital for effective management of certain marine fishery resources."

This case illustrates a basic application of remote sensing of temperature and color to describe the surface marine environment. Reseachers were able to identify areas that optimize conditions required for anchovy spawning. The synopticity of the data enabled them to obtain information on ocean dynamics and to record surface activity that was not detectable by shipboard observation. Water body movement is not consistent from year to year, and satellite images allow researchers to evaluate surface conditions and characteristics.

West Coast Albacore Study

In 1981 the relationships between albacore tuna (*Thunnus alalunga*) and oceanic fronts were examined in a cooperative effort by the Scripps Institution of Oceanography Satellite Oceanography Facility, the Scripps Visibility Laboratory, the National Marine Fisheries Service, the California Department of Fish and Game, the

Oregon Department of Fisheries and Wildlife, and the local fishing industry (Laurs et al., 1984).

An oceanic front is defined as a boundary separating two water masses. Nutrients, forage and fish are frequently found in higher concentrations in these waters. Hydrographic characteristics may change across fronts, resulting in temperature, salinity, and density gradients. Distribution of marine life and suspended or dissolved particles may also vary. Of interest here is the effect these fronts have on the aggregation of albacore tuna, a commercially valuable species.

Concurrent satellite and fish catch data were obtained during periods of heavy fishing activity off the coast of California (August - September, 1981). Data from three NIMBUS-7 passes over California coastal waters and one pass over a region off the coast of Washington and Oregon were collected from the Coastal Zone Color Scanner and processed at the Scripps Visibility Laboratory. Infrared temperature data from corresponding AVHRR overpasses were obtained from the archives at Scripps Satellite Oceanography Facility and were co-registered to ground control points on the CZCS data, rendering the two sets of images geographically identical. Albacore catch data were recorded in the daily logs of participating fishermen. Fishing vessel positions were recorded at the beginning of each day and catches were normalized to 150 line-hours, typical of a full day of effort by albacore trolling or jig boats. Catch data covering a period two days prior to and two days following satellite passes were divided into quartiles and plotted on the satellite sea surface temperature and pigment concentration images (Figs. 6 and 7) (Laurs et al., 1984).

Data analysis revealed that albacore congregate in commercially fishable quantities in areas characterized by warm, blue oceanic waters near temperature and color fronts at the seaward boundary of coastal water masses. Relatively intense fronts associated with persistent upwelling are preferred. It was demonstrated for the first time that albacore favor shoreward intrusions of oceanic water. Offshore, albacore tend to aggregate in waters marked by color fronts but lacking temperature gradients, due perhaps to seasonal warming (Laurs et al., 1984).

The use of AVHRR and CZCS data enabled scientists to draw new conclusions on the environmental preferences of albacore. In the past it was generally believed that the restriction of albacore to an optimum temperature range or areas of frontal temperature gradients was in response to the physiological imperatives of thermoregulation. However, new tracking studies indicate there is vertical migration throughout the thermocline during which tuna undergo temperature changes of $5^{o}C$ or more in 10-30 minute periods. It is therefore felt that temperature requirements alone do not sufficiently explain albacore distribution. Albacore are visual predators; this may govern their aggregating activity. They may be unable to capture large, mobile prey in turbid coastal waters and therefore depend upon food that has migrated or been dispersed across the coastal-oceanic water fronts to the clear water on the oceanic side of fronts in the nearshore areas. In offshore regions, albacore may choose relatively productive waters that are clear enough for the detection of organisms (Laurs et al., 1984).

Researchers are satisfied that satellite data can define the environmental limits of spatial distribution of aggregations of albacore tuna, and can do so more effectively than shipboard and aircraft data. Pigment concentrations and turbidity are thought to play an important role in the definition of these preferences, as temperature alone no longer seems to be an adequate explanation. Laurs et al. (1984) state: "While the CZCS image clearly shows an important color boundary, temperature gradients are nonexistent after the onset of seasonal warming. The continued presence of a color scanner in space is critical to the further development and use of such information in fisheries research, management and exploitation."

It has been established that albacore are influenced by oceanographic conditions. Conditions vary in time and space from year to year and in the Pacific Ocean are linked to the Transition Zone. Transition Zone waters separate the cool, low salinity Pacific Subarctic waters to the north from the warm, saline Eastern North Pacific waters to the south. The Transition Zone is narrow in some years with well-defined fronts; in other years it is broad with weakly developed fronts. Migration routes of albacore are associated with the Zone, and therefore experience annual variability. Researchers have found albacore aggregations further offshore and up to six weeks earlier than expected, depending upon the development of the Zone.

Albacore fishermen traditionally fish in warm, blue oceanic waters (Laurs and Lynn, 1977). The use of thermal and color satellite imagery can aid in the identification of these frontal areas, and fishing operations can be directed accordingly, an enormous advantage considering the magnitude of the area involved. Thus, satellite data can be instrumental in both expanding and stabilizing the fishery, by indicating the onset of the fishing season as well as zones of optimal conditions.

Gulf of Maine Plankton Study

In 1983, Charles Yentsch of the Bigelow Laboratory for Ocean Sciences reported on efforts to apply Coastal Zone Color Scanner data to determine the fraction of the total productivity in the Gulf of Maine made by the major frontal mixing regimes (Yentsch, 1983).

Phytoplanktonic organisms constitute the first link of the marine food chain. The chlorophyll content of these organisms is measured with the CZCS and the distribution patterns yield important information on the role of oceanic processes in the regulation of primary productivity.

In 1928 H.B. Bigelow, in his studies of the oceanography of the Gulf of Maine, identified areas which he considered to be highly productive as a result of tidally-generated vertical mixing (low-stability areas) (Fig. 8). Vertical mixing is crucial to phytoplankton growth as it prevents the upper layers of the water column from becoming stratified by seasonal warming. Stratification results in heated surface layers which are more buoyant and therefore isolated from the nutrient-rich lower layers. Well-mixed areas circulate nutrients more effectively and encourage greater primary productivity.

Garret et al. (1978) calculated the degree to which tidal activity mixes the water column. Tidal activity, they found, is responsible for some mixing on Georges Bank, Nantucket Shoals, and to a lesser degree, the Bay of Fundy and along the coast of Nova Scotia. In the other areas of the Gulf of Maine, they found the tidal velocities to be too low or the water depth too great for mixing to be explained by the tidal effect. However, even in the areas in which mixing is due to tidal activity, this activity is not sufficient to account for the degree of mixing observed. For instance, Garret's tidal model predicts that on George's Bank destratification would occur at about 30-40 meters; in situ measurements show that it occurs at about 60 meters. This suggests that something other than the tidal process destratifies the water column.

A color image from the Coastal Zone Color Scanner from 14 June 1979 (Fig. 9) measuring chlorophyll-a content shows high phytoplankton concentrations on Georges Bank, Nantucket Shoals, and the areas off the coast of Maine. These areas correspond to Bigelow's low-stability areas. The corresponding CZCS thermal infrared image (Fig. 10), shows that the cold (or well-mixed) areas are coincident with the higher-productivity zones in the first image. This suggested to Yentsch that oceanic frontal activity is responsible to a major degree for vertical mixing in these areas.

Assuming that surface chlorophyll content is a valid indicator of water column productivity, Yentsch approximated the contribution of these areas to the total productivity of the Gulf by calculating: (a) the area of destratified water regions; (b) the total area of the Gulf of Maine (1.4 x 10^5 km); (c) the percentage of this whole occupied by mixed regions with thermal fronts (30%, of which Georges Bank accounts for half); and (d) the difference in chlorophyll content between frontal and non-frontal areas. The frontal areas, due to their high productivity, produce about 2 1/2 times more than the non-frontal areas, or 30% of the Gulf is responsible for almost 2/3 of the total production. He emphasizes that these results could not have been determined without the synopticity provided by satellite imagery (Yentsch, 1983).

Fifty years ago the Gulf of Maine was one of the most comprehensively studied ocean areas in the world. It was generally accepted that Bigelow's theories accurately described oceanographic processes and characteristics. However, with the advent of remote sensing and the availability of detailed surface data far surpassing in scope that provided by traditional shipboard sampling, researchers developed new interpretations of what actually occurs in Gulf waters. This case, though of elementary strategy, employs satellite synopticity to not only confirm but augment existing hypotheses, thereby contributing to the greater understanding of the dynamics of biomass and primary productivity in the fishery.

CHAPTER III

PERIPHERAL AND POTENTIAL APPLICATIONS OF REMOTE SENSING TO FISHERIES

The six cases in the previous chapter illustrate the use of satellite-borne sensors to derive synoptic information aimed specifically at finding fish or defining the environmental requirements of fish. This chapter will present some peripheral applications of remote sensing that are less immediately directed towards location and distribution of fish, but which nonetheless provide information on factors influencing the state of the fishery. Some situations in which remote sensing has the potential to remedy existing informational gaps are introduced as well.

Remote Sensing and Fisheries Research

The initial step in any fisheries endeavor, whether ultimately benefiting research, management, industry, or a combination of the three, is to obtain information elucidating the biology and behavior of fish and their relationship with their environment. It is important to remember that fish are not a separate entity. Their health, viability and very presence depend upon a host of interrelated factors: salinity, temperature, food supply, water circulation, response to environmental stress, fishing pressure, etc. Their habitats range from open ocean to estuaries and are constantly affected by the external pressures of pollution, flooding, terrestrial runoff and alteration of the coastal and offshore environment.

The primary requisite for successful utilization of satellite-generated data is the knowledge of how surface features relate to the fishery. In order to establish these relationships it is essential to know the life cycles, spawning behavior, migratory patterns, feeding habits, environmental preferences and physiological requirements of fish. The more plentiful the biological information on the fishery, the stronger and more comprehensive remote sensing becomes as a research tool.

Several studies warrant mention here as indicators of how remote sensing adds new dimensions to understanding the marine ecosystem.

Plankton Detection

Chlorophyll-a concentrations of phytoplankton populations are detected by satellite-borne sensors. It is therefore possible to record occurrences of phytoplankton in the oceans. This capability has proven useful in several instances. It should be noted that phytoplankton have a short life span (measured in days) and as such it is virtually impossible to obtain distribution and transport information of phytoplankton with shipboard sampling techniques.

Phytoplankton observations need the synopticity provided by satellite imagery. Gower et al. (1980) used LANDSAT data to demonstrate that plankton occur in patches formed by eddies of 10-100 km in diameter. These eddies would be difficult to detect with standard oceanographic methods. Thermal infrared data is useful in identifying oceanic fronts and water boundary dynamics in areas like the California Current and the Gulf Stream where thermal contrasts range from 2.0 to 6.0^{o}C. However, many of the Earth's oceans are isothermal and temperature differences are too slight (0.1-0.5^{o}C) to be detected by thermal infrared sensors. Gower et al. (1980) suggest that in the future surface phytoplankton patchiness might be used to chart ocean circulation on a global scale, while at the same time yielding valuable information on biomass and primary productivity.

The timing of the spring bloom of phytoplankton is governed by environmental conditions and as such could be used as an indicator of successive phytoplankton and zooplankton populations. Larvae of marine organisms are dependent upon having the right size food (plankton) at the right time. Plankton that arrive too early or too late in the season cause a food mis-match (Nelson et al., 1977), resulting in heavy larval mortality and a seriously diminished year class. An environmental monitoring program designed to yield information on the state of the oceans' productivity would be beneficial in estimating year class strength and constructing fishery models for manangement. Ships that are presently dependent upon imprecise random sampling methods could be deployed to sample egg and larval populations in response to prevailing conditions.

Monospecific blooms of certain plankton are the cause of red tides. Though not always red, and not necessarily tidal in nature, the effects of red tides can be devastating to the coastal environment. They are responsible for fish- and seabird-kills and can ultimately affect humans through toxic accumulation in shellfish. Although plankton bloom initiation is not yet well understood, it is dependent upon and maintained by oceanographic conditions (Steidinger and Haddad, 1981). Blooms are transported by wind and currents, and can cover large geographic areas. A comprehensive shipboard research program would be costly and logistically awkward, but without a viable monitoring program data are often available only before and after bloom initiation and interpretation must therefore be extrapolated.

Recent studies have focused upon using satellite imagery to identify phytoplankton blooms (Steidinger and Haddad, 1981). GOES infrared imagery has been helpful in identifying the corresponding water masses, but is limited to winter months in Florida coastal waters which are isothermal from June to November. CZCS imagery has been used to identify blooms, and both thermal infrared and color imagery can be helpful in directing shipboard sampling operations. Researchers are working with satellite imagery to develop the capability to predict the timing and sequencing of plankton blooms.

Estuarine Habitat

Habitat is the cornerstone of marine productivity. Each and every species has an ecological niche within which its biological requirements must be satisfied. Habitat is defined by a variety of characteristics, among which are bottom and vegetation type, depth, salinity, temperature, and water quality. Marine life depends upon different habitat availability at different stages in life; there is a complex network of relationships between a species and its habitat as well as between different species. These relationships include food availability, predation, spawning activity, egg and larval transport, physiological tolerances to temperature, salinity and oxygen, and substrate type and vegetative cover, all of which may vary temporally or geographically. If habitat is eliminated or altered beyond a species' ability to adapt, survival is jeopardized.

Estuaries, those areas of a river where saline oceanic waters interact with fresh water, are highly productive ecosystems and meet habitat requirements for an abundance of coastal marine life. Estuarine well-being, and thus the well-being of its numerous inhabitants, is affected by the ever-changing coastal environment. As human population in coastal areas increases so too does stress on the estuarine environment. Stress is caused by alteration in topography and in freshwater flow mechanics, and by pollution. The effects are manifested in shifts in species composition (heartier, less desirable, more tolerant species lower in the food chain survive), eutrophication, poor water quality, and decimation of available estuarine habitat.

The Florida Department of Natural Resources has recognized the impact that alteration of the environment has had on coastal areas and thus on fishery habitats, and has supported research to monitor, inventory and assess these areas on a continuing basis (Harris et al., 1983). LANDSAT imagery has been used to classify vegetation in the Charlotte Harbor area, and once the desired level of accuracy is developed, applications will extend to other areas. CZCS data will be employed to study fish distribution, recruitment and migration on the west Florida Shelf. The purpose of this research is to document environmental alteration and its effect on the fishery, then through management and legislation mitigate devastation in order to restore and enhance the coastal zone.

Identification and Monitoring of Study Areas

The SUPERFLUX program, initiated in 1980, sought to determine the influence of the Chesapeake Bay Plume on the contiguous continental shelf. LANDSAT data, archived since 1972, provided historical perspective enabling researchers to define their area of major concern. Research was directed towards developing a long-term program for assessing and managing the ecosystem and for monitoring and planning strategy to combat toxic spills and related occurrences (Thomas, 1981). Plume waters, entering the ocean from the enclosed Chesapeake Bay, are high in concentrations of suspended particles which provide both nutrients for and contaminants of primary production. The released nutrients stimulate primary productivity which in turn increases biomass and production higher in the food chain. The plume system becomes biologically more active than neighboring shelf waters and generates greater fishery potential. Surface truth and vertical sampling were provided by research vessels directed in response to airborne remote sensing. Satellite remote sensing made an important contribution in the identification of the target area.

The Large Area Marine Productivity-Pollution Experiments Program (LAMPEX) is a series of studies being conducted by the National Marine Fisheries Service and the National Aeronautics and Space Administration to hasten and perfect the operational use of remote sensing to increase knowledge of processes relating to the marine ecosystem. The study encompasses the continental shelf area of the Eastern United States from the Gulf of Maine to the Gulf of Mexico. Several individual studies, begun in 1979 and including the SUPERFLUX Program mentioned above, comprise the whole. Sea truth data obtained from shipboard observations is integrated with data from satellite and airborne sensors to monitor and assess the region with respect to: 1) the spring bloom of phytoplankton; 2) patchiness; 3) year to year differences in spatial patterns; 4) the flux of material and contaminants from the estuaries; 5) frontal systems; and 6) the circulation and continuity of such systems as Georges Bank with respect to year class survival of larval fish (Thomas, 1981). With the synopticity and frequent coverage made possible by remote sensing, research vessel effectiveness should increase dramatically.

Pollution

Pollution from toxic substances introduced into the oceans by human activity threatens the delicate balance within the marine environment. Large amounts of industrial contaminants are discharged into coastal areas and enormous quantities of petroleum products and wastes are transported across and spilled or dumped into the oceans. Vytautas Klemas at the University of Delaware has studied estuarine dynamics and has constructed a model to predict the effect of hydrographic circulation in the Delaware Bay and adjacent shelf areas on the transport and dispersion of oil slicks and surface pollutants (Klemas, 1977). Satellite data was instrumental in redefining classical theories of estuarine circulation by providing information on several types of frontal activity during different stages of the tidal cycle. Models of this type can be helpful in gauging the effects of pollution on various marine ecosystems.

Climatic Variability

Recent years have witnessed degrees of climatic instability with temperatures and coastal currents experiencing variability (Chamberlin, 1979). This variability can frustrate standard research methods, which must infer change from a series of laborious field experiments. With the advent of satellite imagery, researchers can capitalize on the vast amounts of data available, its timeliness and synopticity, and then direct research accordingly. Instead of conducting a broad, random sampling program that may or may not reveal variations and inconsistancies they can immediately focus upon issues central to their research. Early signs of some climatic fluctuations can be detected by warming surface temperatures. Although the dynamics of events such as El Nino are not fully understood, response to early warning signals can result in a greater state of preparedness, both for the fishery and for the communities most affected by its climatic vagaries.

Remote sensing from satellites provides a solution to a basic need of environmental research: the ability to synoptically view large geographic areas on a regular basis. Data is constantly collected and archived. It can be retrieved for historical comparison. As problems arise, there is a large body of pre-existant environmental data. Up-to-date information can be obtained as needed. Remote sensing enables researchers to inventory coastal areas, assess these areas with respect to biomass and productivity and monitor these areas to detect change. This in turn allows researchers, managers and fishermen to respond to change.

Remote Sensing and Fisheries Management

Fisheries management is the mechanism by which research information is processed and emitted in the form of management plans to insure the standing crop while providing enough harvestable resource to maintain the industry. As such, it can benefit from effective application of remote sensing to research endeavors with timely decision making and the capacity to respond to change. Regulation is an aspect of fisheries management which directly impacts the fisherman. There is a certain mystique about the rationale of fisheries management. With increased biological and environmental information, biomass determination and thus regulation can become more consistent and less aggravating to the fisherman. If response to fluctuating year classes of a particular species can be predetermined, and one means of regulation adhered to, then fishermen will not incur the added expense of multiple gear. Simplification of management schemes will reduce financial strain on the industry.

Fishery management is also concerned with policing the fishing grounds. Vessel encroachment on territorial waters or closed fishing areas is subject to penality by law. Remote sensing has potential value in vessel monitoring. Multispectral scanners such as those flown on LANDSAT but with higher spatial resolution might be capable of detecting fishing vessel activities in restricted areas but the excessive amount of data which would be generated by such sensors would be prohibitive. An alternative approach might be to equip vessels with a "black box" type of device designed to signal the ship's whereabouts at regular intervals. Although this technique warrants mention, it lies more within the realm of communications than that of remote sensing and will not be formally discussed. Ultimately, it could be an economical method of directing enforcement campaigns, securing adherence to regulations, and increasing the effectiveness of management strategy. Widespread implementation of such an enforcement technique requires further development, and should not be discounted as being of real benefit to fisheries management.

Remote Sensing and the Fishing Industry

Fishing Chart Programs

In response to the success of the anchovy and albacore studies, two experimental programs providing satellite-generated environmental charts for fishermen were initiated on the West Coast. The underlying rationale was that if fish were consistently located in areas of similar water temperature and color, then these areas could be identified with satellite imagery and fishing operations directed accordingly.

The earlier program which began in 1975 employs thermal infrared data from the VHRR and AVHRR of the TIROS-NOAA series. Sea surface temperature charts of selected Pacific Ocean areas off the U.S. west coast were provided by the National Oceanic and Atmospheric Administration's National Earth Satellite Service's Satellite Field Services Station (NOAA/NESS/SFSS) in Redwood City, California. Real-time information was charted to describe thermal boundary activity helpful to fishermen of albacore, skipjack tuna (*Euthynnus pelamis*), yellowfin tuna (*Thunnus albacares*), and salmon (three species: coho, *Oncorhynchus kisutch*; king or chinook, *Oncorhynchus tshawytscha*; pink, *Oncorhynchus gorbuscha*).

Initially, chart distribution was conducted via telephone telecopier and the U.S. mail. However, this system caused delays that diminished the effectiveness of the real-time nature of the information. Radio facsimile is now used, and charts are broadcast directly to the fishing vessels. Two major problems exist that are detrimental to the overall success of the program. First, shipboard receiving equipment can be prohibitively expensive to small boat owners. Second, availability of data is dependent upon cloud-cover. Nevertheless, since the inception of the program, fishermen report that they spend less time at sea and consume less fuel, resulting in sizeable savings (as much as $500,000 for 200 albacore and salmon boats in 1975; Breaker, 1981).

The second program, implemented during the 1981 and 1982 fishing seasons was sponsored by the Jet Propulsion Laboratory of Pasadena, California in cooperation with the Ocean Services Division of the National Weather Service. Experimental charts were generated from both conventional operational sources (Navy Fleet Numerical Oceanography Center and the National Weather Service) and experimental satellite sources (CZCS ocean color, NOAA-6 sea surface temperature and GOES weather circulation features), prepared by an experienced marine forecaster and transmitted by radio facsimile directly to the fishing fleet. These experimental charts include information on key isotherms, color boundaries, convergence and upwelling areas and mixed layer depths. An additional experimental Five Day Outlook summarizes fisheries related environmental ocean conditions, emphasizing deviations from normal conditions that might adversely affect an unaware fleet (Figs. 11 and 12). This outlook supplements existing operational weather charts and Five Day forecasts available to general users. Charts are generated to cover areas of the Easten Pacific Ocean from the Bering Sea to the Equator, and to approximately 160°E (U.S. NASA, 1981b). These areas host salmon, albacore, tropical tuna and general fisheries. The program design enabled fishermen to utilize a suite of information to select optimum fishing areas, gear and tactics, and resulted in fuel savings of up to 30% (McCandless, 1984).

Charts containing oceanographic information compiled from satellite-generated data help fishermen find fish. Chart programs implemented on the East and West Coasts, the Gulf of Mexico and abroad have resulted in sizeable savings to fishermen. These savings, reportedly as great as $2.25 million for Atlantic swordfishermen in one season, are the result of drastic reduction in fuel consumption made possible by significant information on surface conditions (Ballou, 1983). The decrease in search time greatly increases the efficiency of fishing operations. Pelagic fisheries benefit most from the charts, as surface features best reflect the habitat of these species. For midwater and bottom fisheries further research is needed to correlate surface and subsurface conditions. As ocean dynamics are better understood, inferences can be made that help locate cold bottom areas with mild current activity sought by lobstermen and red crab fishermen (Chamberlin, 1977b). Other, stronger currents associated with Gulf Stream rings and eddies can similarly be detected and avoided, and fishermen, with information on the direction and strength of bottom currents can more selectively set their gear.

Other Potential Industrial Uses

Heavy seas generated by distant storms often belie the calm, cloudless picture of a satellite image. Improved sea state detection by satellite sensors could result in greater safety at sea, of the utmost importance if one is far from land in a relatively small vessel. This applies to both fishermen and fishing gear. Human safety is better protected when a ship's captain can avoid gales and heavy seas. Gear integrity can be maintained if it is not deployed in areas where strong currents prevail. Gear damage and loss occur frequently and repairs and replacement are costly. Insurance rates for ocean going vessels are high, and improved safety conditions may result in appreciable savings. Vessel operating costs are also high - Alaska crab fishing vessels sustain losses of up to $60,000 per day on non-performance days (Montgomery, 1980).

Remote sensing can also benefit fishermen by increasing the appeal of underutilized species. If these species are easily located in fishable aggregations, they can be harvested with minimal effort. There are species (i.e., squid) not favored by Americans for which a large market exists abroad. Consumers world-wide can benefit from greater protein availability as the harvest of underutilized species is increased.

Also, fish will be fresher; as fishing becomes more efficient, steaming time is decreased, and the length of time fish must be stored in the vessel's hold is reduced. Fish processors can benefit from stabilization of the industry as the ease of finding fish increases. A steady, or at least predictable, flow of fish into processing centers would have economic ramifications throughout the community.

CHAPTER IV

DISCUSSION

Synthesis

In considering the case studies and the suggested future applications of remote sensing to fisheries, some patterns emerge.

First, there are three basic types of remote sensing programs related to fisheries: one to test the applicability of remote sensing to the field of fisheries; another to employ remote sensing technology in fisheries research; and a third to provide remote sensing technology for commercial interests. Programs in the first category were designed to determine what information satellite images can produce for the marine environment and its relation to fisheries. The Menhaden Study and the Brazilian Shrimp Study are of this nature. They provided the foundation from which further applications were developed, including environmental programs which peripherally impact fisheries research (Fig. 13). Programs in the second category, exemplified by the anchovy and albacore research on the West Coast, incorporate remote sensing into ongoing research programs. Projects in the third category have made sea surface information available as a fishermen's aid.

Second, the importance of sea surface temperature and ocean color measurements to these studies is underscored (Tables 1 and 2). The AVHRR has consistently and reliably provided SST data which have been used to chart environmental conditions and surface dynamics. The Coastal Zone Color Scanner successfully detects chlorophyll-a concentration which functions as an indicator of primary productivity. Surface color data also aids in the interpretation of shipboard sampling data and registers gross water body circulation. This is helpful in identifying the geographic extent to which sampling should be directed.

The two West Coast studies have regulary used sea surface temperature and ocean color data to aid in established fisheries research programs. Of all parameters detectable from space, it appears that these two are fundamental to the majority of investigations, whether they were conducted in the past, are currently in progress or are projected for the future. Also of great promise, for the future, although not yet experimentally validated, are the scatterometer data of the SEASAT A type, intended to provide information on surface wind stress.

Third, the experimental nature of these applications is evident. The extent to which each has been pursued varies (Tables 1 and 2) and will be discussed further in subsequent sections. For most, the net result has been to determine that (a) a valid, detectable relationship exists, and (b) this relationship can be exploited to provide information on ocean dynamics, primary productivity, frontal location, etc. For the West Coast albacore and anchovy research, the ongoing status of the research programs has allowed for continued application of satellite data. These two studies are closest to obtaining full utilizational impact from the potential of remote sensing from space.

Future of Satellites and Sensors Relevant to Fisheries Oceanography

The principal satellite-derived data relating to fisheries are manifested in the detection of sea surface temperature, ocean color measurements and wind stress determination. This section will focus upon the prospects for the availability in the future of these critical data components.

Satellite-derived SST data

Sea surface temperatures (SST) have been satisfactorily provided by NOAA series AVHRR observations. These products should be available on a continuing basis well into the future, as the AVHRR is a principal component of the polar orbiting operational environmental satellite system. There are plans to improve the AVHRR, but the instrument will remain basically the same, providing the same kind of data it has in the past. The only uncertainty with respect to the AVHRR is whether or not NOAA should reduce its polar orbiting satellite set from two to one (U.S. Department of Commerce, 1985g). It appears this is a budgetary dilemma that must be resolved annually (Schneider, personal communication). In the event that two satellites are maintained in polar orbits, a malfunctioning unit would reduce coverage from twice to once a day, until that unit is replaced. In the worst possible case, a solitary NOAA satellite failing in orbit would result in as many as 120 data-free days until replaced by a stand-by unit. All in all, the future of the AVHRR seems relatively secure, and SST data should be available to researchers with no major discontinuities into the foreseeable future.

Satellite-derived wind data

NROSS, the Navy's ocean sensing satellite mission will place the NSCAT scatterometer in orbit in 1989. The information it will acquire on surface wind activity will alleviate problems created by the untimely demise of SEASAT. With the NSCAT measurements available, researchers will be able to resume the interrupted studies on surface layer transport that seemed so promising for fisheries research.

The European Space Agency (ESA) plans to launch the ESA Remote Sensing Satellite (ERS-1) at about this same time. Various instruments on this mission will be of interest to oceanographers including an active microwave scatterometer for wind stress measurements (Joint Oceanographic Institutions, 1985).

Satellite-derived ocean color data

Early color remote sensing utilized LANDSAT MSS data. The CZCS is better suited to marine studies, by virtue of the addition of the blue channel, by the higher precision offered with narrower bandwidths in the other channels, and by increased data collection over ocean areas. The sophistication of this later sensor has resulted in data that is uniquely relevant to studies of the oceanic (and therefore fisheries) environment, although resolution is somewhat coarser. This is the sensor that has enabled researchers to draw new conclusions and pursue remote sensing in fisheries to the greatest extent.

The Ocean Color Imager (OCI) has been designed to improve upon and replace the Coastal Zone Color Scanner which has far exceeded its life expectancy. However, the future of the OCI is extremely tenuous, an unfortunate situation as its inclusion in the proposed space package would assure a full complement of fisheries relevant sensors.

Planning and deployment of the sensor will take approximately five years from the time funding is granted. The earliest possible launch, if all goes smoothly, is on either the NOAA K or the French SPOT 3 satellites in 1990. Subsequent possible launches would be on NOAA M in 1992 or on the space station's polar orbiting platform in 1993. Due to orbit constraints the OCI must be mounted on an afternoon vehicle.

It is unlikely that the Coastal Zone Color Scanner will provide much data in the future. There will most certainly be a period in which no ocean color data will be available. If the OCI is not funded, the next possible ocean color data will originate from the Moderate Resolution Imaging Spectrometer (MODIS), an experimental color imager proposed by NASA for the polar platform. MODIS is still under development, and may or may not have the OCI incorporated into its design (U.S. Department of Commerce, 1985h). Although MODIS would once again make ocean color data available, the sensor will be experimental, and problems encountered with the CZCS will continue (lack of an operational color imager, data availability of uncertain duration, etc.).

The OCI is a NOAA initiative. While NASA continues to perform basic research on development of the sensor, funding for the entire project must originate with NOAA (U.S. Congress, 1985b), along with a committment to maintain the OCI in an operational capacity. As such, the OCI would require funds every year well into the future. The OCI was included in the fiscal year 1987 in-house budget submitted to NOAA. It was rejected in the first cut, but its proponents intend to resubmit it. If it again fails, it will be proposed for Fiscal Year 1988 (Schneider, personal communication). The sensor has high priority at the National Marine Fisheries Service. Another branch of NOAA, the Office of Oceanic and Atmospheric Research, identifies the OCI as being of moderate priority - a mid 1990s launch would be sufficient for their needs (U.S. Department of Commerce, 1985d).

In general, remote sensing programs of the future will benefit from the increased flexibility made possible by developments in space technology. The space shuttle and the space station with its orbiting platforms will provide alternative means of maintaining sensors in space. The capability to repair or replace malfunctioning units greatly extends the life expectancy of space instrumentation. Studies are now being conducted to determine the cost effectiveness of the various vehicle options for future remote sensing missions.

If the proposed complement of remote sensing instrumentation does indeed become operational, fisheries stands to benefit from the increased availability of data relating to the oceanic environment. However, any increase in the quantity of data creates problems of another nature. A very real concern for the future is the amount of data that will be generated by the new sensors. Provisions must be made for collecting, processing, storing and disseminating all data in a timely manner. There are currently 2000-4000 data sets to be dealt with per day. This number will increase to about four million data sets per day in the future (Ocean Science News, April 1, 1985). The Working Group for Science and Mission Requirement of the Earth Observing System (EOS) focuses on the need for a highly developed information system to handle this extensive remote sensing data (US NASA, 1984). The system should provide access to past, present and future data, which should be uniform in format. Processing systems worldwide should be compatible for maximum exchange of data. Only with the capability to process satellite-generated data, can researchers obtain maximum usefulness from remote sensing techniques.

Problems Limiting Remote Sensing Usage in Fisheries

In Chapters II and III the potential of remote sensing has been presented. Not only has it been shown to be of significant potential use in fisheries research, but substantial dollar savings have been suggested as well. Patterns emerging from these studies were summarized in the early part of this chapter, followed by a section on current plans for future satellites and sensors. Inconsistencies between the promise of the research programs and the prognosis for the future immediately arise. Given the clear financial and research advantages indicated by the studies reviewed why is the future so poorly defined? Why has not the OCI been funded and, for that matter, not yet been launched? Why are there not more programs delivering SST charts to the fishing community? Why has remote sensing not been integrated more thoroughly as a tool into fisheries research?

Problems exist with respect to remote sensing as an evolving technology. Some of these are specific to remote sensing of the oceans, others are inherent in any developing technology. These will be discussed below but they do not appear to be the problems constraining the use of the data. The latter appear to be of a more political or educational (within the user community) nature. These will be dealt with subsequently.

Technological Problems

The primary limitation of satellite imagery in applications to fishery research is the inability to penetrate much beyond the surface of the ocean or to "see" through cloud cover. On the average, the waters of the US east coast are clear about 25 per cent of the time, with substantially less coverage in the winter than in the summer months. Newer microwave sensors which can "see" through the clouds are being developed but are still in their infancy.

Research efforts have been thwarted by insufficient satellite coverage (especially the use of CZCS color data), either by sensors that are periodically deactivated, or by time lapses that are a function of orbit configuration. Often it is not possible to obtain complete coverage of a given area under similar conditions, if that area is composed of two or more adjacent scenes which may be separated in time by hours or days (LANDSAT data), depending upon the characteristics of the orbit. Parameters measured by and areal coverage of one satellite may vary from those of another, often making it difficult to obtain information for comparative studies (Karszenbaum, 1983).

Although existing technology provides satellite images on a regular basis, few individuals have the expertise to use these data. Researchers exploit satellite technology on an individual, per case basis. There is little standardization in research development, and refinements are accomplished in a haphazard way, as the need arises.

There is undoubtedly much duplication of labor. The experimental nature of satellite imaging also results in discontinuity of data. Considerable resources were invested in the SEASAT mission, and its early termination resulted in abandoned studies. It is difficult to plan a comprehensive research program based upon data of uncertain duration.

Political and Organizational Problems

Domestic

In times of financial stress, funding is difficult to obtain; competition is fierce. The CZCS was funded at a propitious time for new programs, without full scientific justification. The proven utility of CZCS data should help pave the way for the OCI, but allocation of funds for science has become much more stringent. And though the future of remote sensing seems to lie within the realm of interdisciplinary studies, the National Science Foundation, a primary source of money for scientific programs, exhibits some disinclination to participate in interdisciplinary programs (Clark, personal communication). Another problem has been the lack of a concerted effort in which oceanographers as a group stress the need for the OCI and other sensors much as the astrophysics community has done for their programs. The recent Joint Oceanographic Institutions, Inc. (JOI) report (JOI, 1984 and 1985) is a step in this direction.

Political emphasis in the United States is shifting. Where once education and scientific research were seen as primary objectives for the good of the nation, stress is now placed upon national security and defense. Much sought after dollars are being channeled into the military; space technology and remote sensing data, by virtue of their classified nature, become inaccessible to the civilian community. In addition, as much as thirty percent of NASA's shuttle flight program over the next ten years will be dedicated to military missions. Launch, repair and modification costs are paid for entirely from NASA's civilian budget (Smith, 1985). This directly impacts the OCI which was sacrificed at NASA in order to save the TOPEX mission in a battle for very limited funds (Clark, personal communication).

International

Political and organizational factors greatly influence accessability to sophisticated research methods. Third world nations, heavily dependent upon small scale fisheries are far removed from satellite technology. The fishing operations are too small, the technology too remote. The United Nations' Food and Agricultural Organization (FAO), an organization primarily concerned with resource development in these nations, has only recently evinced an interest in remote sensing and its application to fisheries. The FAO is an ideal vehicle for promoting fisheries projects on a regional basis for countries that lack the technological wherewithal to initiate and sustain such programs. However, instead of assuming a prime motivating role in the implementation of remote sensing projects, the FAO appears to have chosen the more conservative approach of waiting until the efficacy of remote sensing as a fisheries research tool has been established.

Even among technologically developed nations disparity exists. In the Soviet Union government subsidization promotes intensive fishing activity and provides Russian trawlers with state-of-the-art fisheries information. In the North Sea, the fishing grounds for much of the Russian fleet, British fishermen, pursuing their solitary profession, do not have access to a vast, technologically oriented support system (Cracknell, 1983). It is beyond the scope of this paper to address the issues of equitable technology allocation and resource distribution but these are concerns that will inevitably be affected by the widespread use of satellite technology.

Other political factors inhibit long range planning for future satellite missions in the international arena. Foreign interests, many largely subsidized by their governments, are hesitant to enter into financial accord with the United States when they encounter difficulties with respect to appropriations, due to the structure of the U.S. budgetary and legislative systems. Problems are compounded by the United States' "open skies" policy, which makes all data obtained from U.S. civilian satellite missions available to users on a nondiscriminatory basis (Dickson, 1985). Foreign commerical enterprises may be bound by these licensing conditions, and thus may be reluctant to invest in joint ventures with the U.S.

Managerial

The fisheries management process, as it is currently structured in the United States, is slow and laborious. Management plans emerge after long and complex deliberations among the interested parties. As information becomes more readily available the system must be redesigned to allow for expedient and equitable regulation. Only then will the state of management accurately reflect the state of the technology.

Industrial-research cooperation

Problems also exist with respect to the application of remote sensing to the fishing industry. Most problems may be resolved as remote sensing becomes operational, but the nature of these problems may also delay operational status. There is a great need for cooperation between fishermen and researchers in order to maximize the utility of remote sensing. Fishermen are understandably reluctant to divulge information on their location and the success of their fishing operations. As a result, a "black box" has been proposed which would enable fishery researchers to receive up-to-date information on location, fish availability, sea state, etc., without compromising the individual fisherman or risking what may be a competitive edge (Chamberlin, 1979). This would be helpful in providing sea truth for fishery models, including catch per effort studies.

An Example: The Status of SST Charts

A prime example of the organizational difficulties yet to be surmounted is the lack of viability of a commercial enterprise dedicated to providing fishing charts to the industry. A chart program of this nature would be a logical extension of the potential of remote sensing technology to the fullest degree - a self-sustaining commercial program geared towards increasing the efficiency of the industry.

Foremost among the problems are the costs incurred in initiating such an operation. Effective support of the financial burden would require almost total participation within the fishing community. Equally important is the very nature of the industry itself which has historically been capital-intensive. The reluctance of fishermen to invest further in an ever-changing atmosphere plagued with uncertainty (depleted stocks, escalating operational costs, international territorial restrictions, etc.) is understandable. Experimental chart programs on the West Coast rely upon both ocean color data and the more readily available sea surface temperature data. Any alteration of data availability would require extensive reorganization within the system.

These factors will be considered in greater detail in the following pages.

Problems of Perceived Value in the Application of Remote Sensing to the Fishing Industry

Sea surface temperature and/or ocean color charts are presently provided to fishermen on an experimental basis. The charts have been recognized as being of benefit, but there is some question as to the value the fishing community places upon these aids and its willingness to pay for the service.

On the West Coast, fishing charts are thought to save fishermen hundreds to thousands of dollars. However, at this time no quantative studies have determined the exact savings due to reduced search time (Montgomery, personal communication). Economic studies must be conducted in order to determine if a commercial venture aimed at providing these charts on a subscription basis can succeed. West Coast fishermen appear to be unwilling to pay for the service that has, to this point, been provided free on an experimental basis by the U.S. government. Several factors seem to contribute to this reluctance. First, fishermen equate the charts with the weather products historically provided without charge by the National Weather Service, and seen as a kind of inalienable right. Second, fishermen do not function as a unit. Big money fishermen, operating on experience and instinct, have established a firm competitive edge over less successful fishermen. They openly oppose the fishing charts, seeking to prevent the elevation in status of others who, fortified with the charts, become more productive, and thus generate an atmosphere of increased competition (Clark, personal communication). Another problem is the inability to distribute charts in a rapid manner, before the information is too old to be useful. This obstacle can be overcome, but only with expenditures for shipboard receiving equipment.

New England fishermen are somewhat hesitant to "go electronic", at least until its utility is firmly established (Dykstra, 1979). However, unless the chart programs are effectively tested by these very fishermen it will be difficult to estimate their value. The expense of equipment necessary to initiate and maintain an electronically sophisticated fishing operation and thereby take full advantage of satellite technology is in many instances prohibitive. The retrieval and processing of data and the distribution of charts can be laborious and time consuming, which diminishes the "real time" nature of the data and thus its applicability. The solution to this problem is an investment in highly sophisticated equipment (receiving stations, data processing equipment and electronic transmitters), which may not be justifiable until the program's future is guaranteed.

The University of Rhode Island, in conjunction with the National Marine Fisheries Service, provided sea surface temperature (SST) charts, via mail, and on an experimental basis, to the operators of commercial, charter and recreational fishing vessels in the Northwestern Atlantic (Fig. 14). Upon termination of the project, questionnaires were sent to 165 participants in an attempt to gauge the effect of the program on the fishing community (Fig. 15). Respondents expressed enthusiasm for the charts and an interest in continuing to receive them in the future. The overwhelming majority stated that they were willing to pay at least $50 per year to receive these charts on a subscription basis; only one respondent adamantly maintained that all costs should be borne by the government. Charter boat operators and recreational fishermen were willing to pay more than commercial fishermen for the same service. As a group, the charter boat operators were willing to pay an average of $165 per year and recreational fishermen $133 per year. Commercial fishermen were willing to spend an average of $100 per year; however, 67 per cent of the commercial fisherman indicated that $52 per year was the maximum expenditure for fishing charts that they were likely to make (the average for this group is inflated by two commercial fishermen willing to spend $250 per year, and one willing to spend $100). Refer to Table 3 for more detail (University of Rhode Island, Marine Advisory Service, unpublished data).

The Cost of a Commercial SST Program Versus the Benefits and the Income

Given the evident interest in continued participation in the experimental chart programs, the costs of establishing a commercial venture were investigated. The question of whether such a venture is commercially profitable has been addressed, based upon the dollar figures that fishermen responding to the URI questionnaire were willing to spend.

Using $100 as the base amount that all fishermen might spend to receive the SST charts, an attempt was made to determine the feasability of establishing a commercial venture to provide the charts to 3400 fishermen. This figure was based upon estimates from various sources: 900 commercial fishing boats, 500 charter boats and approximately 2000 recreational fishing boats for the New England and Mid Atlantic States (Hickox; Christensen, personal communication).

Four possible scenarios are projected, and the costs are tabulated in Table 4. Plan 1 would provide a chart for one scene on a daily basis, and each chart would be delivered by first class mail. Plans 2 and 3 would make two scenes available every other day, Plan 2 via mail and Plan 3 via mail and direct delivery to twenty fishing ports of 25 vessels each, by computer hook-up. Plan 4 would provide fishermen with a choice of three scenes every third day, and information would be disseminated via computer network to 100 ports averaging 34 vessels each.

None of these plans seems to be financially rewarding. Figures were compared for a three- and a ten-year period for each plan. The best possible returns were from Plans 2 and 3 over a ten year period, averaging about $25,000 and $26,000 per year. These returns are relatively modest when compared to other forms of investment for the large sums of capital required to initiate the programs (Vaughn, personal communication).

If, however, the number of participating fishermen could be increased to 6,800, the results would be drastically altered. The same basic investment produces an average annual income of $166,000 and $204,000 respectively for Plans 2 and 3 over a ten year period. Thus, only with substantial participation within the fishing community over an extended period of time can an attractive return on the investment be realized. It should not be assumed at this point that 6,800 subscribers will be readily available. That figure was chosen for convenience to view the trend as the number of participants increases.

A few words of caution are in order. First, this is but a basic query into the commerical possibilities. Certain vital economic factors have been ignored. Not taken into consideration are the value of investment capital in diverse financial fora, market forces, alternative technological methods, inflation, depreciation, and tax structure, to name a few. Second, the figures upon which these scenarios are based are rough estimates. It is difficult to ascertain exactly how many vessels are fishing the waters of the North Atlantic and the number of vessels in each category (i.e., commercial, charterboat, and recreational). The latest compilation of numbers of commercial fishing vessels in the U.S. is based upon statistics provided by the National Marine Fisheries Service for 1977 (U.S. Department of Commerce, 1984). It is difficult to determine the accuracy of these figures. Do they represent only offshore fishing vessels or are ground fishermen who would have little use for sea surface temperature information at this time also included here? Anyone considering a commercial venture should use the estimates presented herein with great caution. The same caution is suggested with respect to the results of the questionnaire upon which these calculations are based. The questionnaire is superficial in nature and lacks specific information on fishing methods, species sought, number and duration of trips, fuel savings, etc. Fifty-six respondents replying in a haphazard fashion, often leaving several questions unanswered should not be the sole foundation of a capital-intensive commercial venture. However, the questionnaire and the vessel estimates are the best available at the moment, and provided a rough framework for analyzing the potential for a commercial endeavor to provide fishing charts which, the fishermen almost unanimously agreed, save time and money.

The questionnaire did provide some valuable insight into the needs of the fishermen, as evidenced in the comments that were made. Many fishermen required greater areal resolution, others were interested in geographic coverage beyond that provided. Several considered the information contained in the charts to be outdated by the time it was received. These factors should be taken into consideration in an attempt to furnish a tailor-made product for the intended users.

A curious pattern emerges upon consideration of the responses to the questionnaire. Although many fishermen concluded that they did, in fact, experience dollar savings due to decreased search time, only a few were willing to spend more that $50 per year to receive the charts. One fisherman calculated his savings to be approximately $5000, but placed a maximum value of $50 per year on the charts.

There appears to be a sizeable gap between the perception of the benefits received from the charts and the value of these benefits to the fishing community. One possible explanation is that although the charts may be perceived as a fishery aid, the inconsistencies of the system render the value marginal. Cloud cover often limits production of the charts, so they are not available on a truly regular basis. The delay in receiving the charts by mail, in conjunction with the fact that if at sea, the fishermen cannot receive them at all may be a major factor. The geographic coverage may not be sufficiently extensive or flexible to excite great interest, or the resolution adequate to meet the needs of many of the fishermen.

These limitations, except for that of cloud cover interference, might be surmountable, but only with additional expense to the fishermen. Chart reception could be expedited by the installation of expensive shipboard receiving equipment. Geographic coverage could be expanded, but only at added cost to the producer, which would in turn be passed on to the fishermen. There is a very real possibility that a chart program would not acquire the necessary subscribers to make the venture profitable.

The fishing industry is currently over-extended and in a state of uncertainty. Costs are escalating, and return on investment is questionable as the harvest diminishes. The very nature of this over-capitalized industry could easily account for its reluctance to invest in itself to an even greater degree.

It becomes evident that, although potentially feasible in terms of dollars and cents, the success of a commercial venture must ultimately depend upon the participation of the industry. The industry is influenced by external factors which are not necessarily based entirely upon financial principles.

Only when these problems have been satisfactorily resolved, and information is available and utilized in a timely fashion will the fishing community be able to realize the full potential of satellite remote sensing.

CHAPTER V

CONCLUSIONS

Satellite remote sensing has the potential to make a major contribution to fisheries research, and by extension, to the remaining components of fisheries. Above all else, remote sensing provides the synopticity which enables researchers to expand their horizons when contemplating the environment of the fishery. With remote sensing it becomes possible to consider the fishery in its entirety. No longer must scientists deal with discrete parts of the whole. Appropriate sensors detect a suite of information ranging from the dynamics of surface layer transport to the productivity of the continental shelf. The concept of space and time in the fishery has been permanently altered as researchers perceive vast ocean and coastal areas on a repetitive basis.

As satellite imagery facilitates the location of commercially valuable aggregations of fish it is the responsibility of management to make use of this same technology to conserve the fishery resource. Fishery resource managers can then respond to the improved nature and timeliness of the information from which they synthesize their strategies. They should deliberate upon the nature of the management machine in order to preserve timeliness throughout the system. If stock forecasts are provided a year in advance, management techniques should be determined well ahead of the fishing season, and have the flexibility to respond to altered circumstances, which could be rapidly detected.

The fishing industry will ultimately benefit from improvements in the management system, and has already benefited by realizing great savings in response to the experimental chart programs. Chart programs have been highly cost inefficient to date. If alternative information sharing solutions can be implemented (i.e., provision of charts to ports on a subscription basis where multiple mailing costs can be avoided), there is hope that a commercial venture could succeed.

Sea surface temperature has been the basic ingredient for most fisheries related studies. It has been the most widely available source of oceanic information and has therefore been exploited to the greatest extent. Fortunately, there seems to be little danger of losing this important capability, as there is a continuing demand by many sectors of the scientific community for surface temperature data.

However, ocean color data has also been shown to be a critical element in the majority of cases presented (Tables 1 and 2), as it provides information on the marine environment beyond that of temperature variation; most importantly, it acts as an indicator of primary productivity which is a salient factor in both the location of fish and the determination of the state of the fishery.

It is the combination of temperature and color data that provides the greatest potential for the use of remote sensing as a fisheries tool. And it is the lack of a continuing source of color data that threatens the very concept of remote sensing for the fishery.

The most striking manifestation of the lack of an operational color imager is that with all the potential inherent in the technology, not one of the uses has been developed to the fullest extent possible. The menhaden and shrimp studies will be excluded from this analysis, as they were designed as applicability tests, and in fact met their objectives; that is, to determine if there were parameters that could be measured from space that would reflect the environment of the fishery. Of the other studies considered, only the anchovy and albacore research on the West Coast approached full utilization of the technology. Of these, only the albacore study was involved with the actual location of fish. As such, the logical extent of the study would be to engender a commercial venture which would enable the technology to pay for itself. This has not happened.

The preceding chapters have testified to the innate potential of remote sensing to provide much needed information to the various components of fisheries. However, after more than a decade of fisheries applications, these applications remain experimental. As the potential has been established, one must attempt to understand why the natural segue into operational mode has not been achieved.

There are several reasons for the inability of remote sensing to attain its full potential in the field of fisheries. The surface layer transport study was cut short due to a technical problem, the failure of the SEASAT mission. This, one hopes, will be rectified in the near future with the launch of the NROSS mission, when the study can be reinitiated. The plankton study in the Gulf of Maine had the potential to develop into a monitoring and assessment program, but the limited availability of CZCS data makes it impractical. The anchovy and albacore studies have utilized color data as fully as is possible, but retain their experimental status due, once again, to the uncertainty of the availability of color data. The chart programs must also remain experimental because, again, there is no guarantee that there will be data to continue the color chart programs, or sufficient industry support to sustain an SST chart program. In order to succeed with a commercial venture, one must generate a market, and that is impossible with a product of questionable duration or one dependent upon a financial foundation of an uncertain nature. The SUPERFLUX program utilized the LANDSAT MultiSpectral Scanner because it provided sufficient data and would continue to do so. The LAMPEX program is dedicated to refining remote sensing techniques for ocean studies, but of necessity the refinement focuses on a sensor that is less suited for the job than one designed specifically for ocean color measurement. The CZCS proved superior to the MSS in meeting the requirements for ocean coverage and spectral bandwidth of oceanographers.

The future of fisheries remote sensing is by necessity poorly defined, as there is no clear indication of which sensors will be available. This uncertainty is largely a result of the political and economic factors discussed in Chapter IV. The need for and value of an ocean color sensor have been recognized, and the sensor has been designed. However, the requirements of fisheries researchers do not seem to be in themselves sufficiently important to generate a new sensor. The two major currently funded sensors relevant to fisheries, the AVHRR and the NROSS scatterometer, exist not as a result of their importance to fisheries, but upon their merit as determined by other sectors of the scientific community. However, one might reasonably assume that since great attention is being paid to the needs of global climate research, and that such research can utilize ocean color data, there is a possibility that the OCI will become a reality. In that event, fisheries researchers will benefit enormously, especially with respect to synoptic ocean color data applied to determining primary productivity which, as an indicator of biomass, has ramifications throughout the fishery.

The approach taken by the Joint Oceanographic Institutions, Incorporated, to phase in the desired satellite missions to minimize financial strain and to aim at providing a full complement of ocean remote sensors, seems reasonable enough. Since the research is to be funded and conducted within an international framework, it follows that applications should lie within this framework as well. Fisheries resources do not recognize national boundaries, and are often common to a region, not a single country. United, under the auspices of such international organizations as the United Nations' Food and Agriculture Organization or the United Nations' Environmental Program, less advantaged nations would have access to advanced technology both for research and resource development that is beyond their individual means.

Until such time that color, temperature and ocean surface activity can be determined from space, the effectiveness of satellite remote sensing in fisheries will be severely curtailed.

In closing, it should be noted that remote sensing cannot stand alone. We will continue to need sea truth provided by research vessel observations. Remote sensing can expand our research capability spatially and temporally, but cannot delve deep into the oceans. As ocean color data and sea surface temperature data combined provide for more impact than either capability alone, so satellite remote sensors and oceanographic research vessels, working in harmony, can provide surface and subsurface information unobtainable by either method individually.

CASE STUDY	PARAMETER MEASURED	DERIVED RESULT	FISHERIES RESEARCH	FISHERIES MANAGEMENT	FISHING INDUSTRY	COMMENT
Menhaden	color	predict distribution	locate fish fish / remote sensing correlation			tests applicability
Shrimp	color	turbidity	fish distribution patterns			tests applicability
SEASAT A	surface wind stress	surface layer transport	stock prediction models	information on state of the fishery		tests applicability
Anchovies	color, temperature	description of surface environment	monitor environment, interpret ship data, direct sampling	information on state of the fishery		application to fisheries research
Albacore	color, temperature	front location	distribution, draw new conclusions on fish behavior	information on state of the fishery	locate fish	application to fisheries research
Plankton	color	chlorophyll a concentration	primary productivity re: upwelling and fronts	information on state of the fishery		application to fisheries research

Table 1. Case studies and results. Heavy lines denote extent to which activity has been pursued

STUDY	PARAMETER MEASURED	DERIVED RESULT	FISHERIES RESEARCH	FISHERIES MANAGEMENT	FISHING INDUSTRY	COMMENT
Plankton patchiness	color	chlorophyll a concentration	ocean circulation dynamics			tests applicability
Plankton distribution	color	chlorophyll a concentration	biomass determination	information on state of the fishery		tests applicability
Red tides	color	chlorophyll a concentration	red tide dynamics	information on state of the fishery		application to fisheries research
Estuaries	color	classify vegetation, surface environment	monitor, assess and inventory	information on state of the fishery		application to fisheries research
SUPERFLUX	color	identify plume area	direct study to appropriate areas			application to fisheries research
LAMPEX	color temperature	chlorophyll a concentration fronts and circulation	monitor, assess	information on state of the environment		tests applicability
Pollution	color temperature	frontal activity	dynamics of pollution dispersal	information on state of the environment		tests applicability

Table 2. Supplementary studies and results. Heavy lines denote extent to which activity has been pursued..

TYPE OF FISHING OPERATION	TOTAL NUMBER OF RESPONDENTS	ESTIMATE OF TOTAL DOLLARS SAVED YEARLY	NUMBER† OF REPLIES	WOULD USE NEXT YEAR†	AMOUNT WILLING TO SPEND / YEAR †						
					$0	$50	$100	$250	$500	$1000	MEAN
Commercial	11	7900*	5	9	0	6	1	2	0	0	$100
Charter	11	3300*	5	11	0	8	0	1	0	1	$165
Recreational	28	6875*	16	28	1	19	0	4	1	1	$133
Other§	6	no responses		6	0	3	0	1	0	0	$100

* Other figures are not comparable, measured in gallons per trip or dollars per day, with insufficient data on trips per year to calculate a dollars per year figure.

† All respondents did not answer all questions.

§ Not fishermen

Table 3. Partial summary of URI/NMFS fisheries questionaire.

Table 4. Breakdown of major costs for providing SST charts.

COSTS

One-time costs		Plan 1	Plan 2	Plan 3	Plan 4
Hardware:	Microvax	50,000	50,000	50,000	50,000
	display	30,000	30,000	30,000	30,000
	hardcopy, xerox	10,000	10,000	10,000	10,000
	IBM PC, xerox each port	—	—	100,000	500,000
	Total one-time costs	90,000	90,000	190,000	590,000
Yearly costs					
Other:	software	20,000	20,000	20,000	20,000
	data	44,000	44,000	44,000	44,000
	hardware maintenance	8,000	8,000	8,000	8,000
	mailing and xeroxing	397,120	199,104	140,544	—
	labor (ports and office)	35,000	35,000	56,960	144,800
	port telephone and copies	—	—	25,620	78,080
	Total yearly costs	504,120	306,104	295,124	294,880
Grand total		594,120	396,104	485,124	884,880

Plan 1: 1 scene daily, processed and mailed

Plan 2: choice of 1 of 2 scenes, every other day, processed and mailed

Plan 3: provide equipment at 20 ports, each with 50 participating vessels, choice of 1 of 2 scenes, every other day, processed and mailed to 2400, xerox to 1000

Plan 4: provide equipment at 100 ports, average of 34 participating vessels at each port, choice of 1 of 3 scenes every third day, no mailings, xerox copy to vessel operator

Table 4. continued...

3 year costs:

	year 1	year 2	year 3	total
Plan 1	594,120	504,120	504,120	1,602,360
Plan 2	396,104	306,104	306,104	1,008,312
Plan 3	485,124	295,124	295,124	1,075,372
Plan 4	884,880	294,880	294,880	1,474,640

For 3 years: total income less operating costs: income = 340,000 x 3 = 1,020,000

Plan 1:	- 582,360
Plan 2:	+11,688
Plan 3:	- 55,372
Plan 4:	- 454,640

10 year income less costs (year 1 costs + 9 x year 2 costs); income is 340,000 x 10 years

Plan 1 : 3,400,000 - 5,131,200 = - 1,731,200
Plan 2 : 3,400,000 - 3,151,040 = + 248,960 (possible profit)
Plan 3 : 3,400,000 - 3,141,240 = + 258,760 (possible profit)
Plan 4 : 3,400,000 - 3,538,800 = - 138,800

With 6800 participating fishermen

yearly costs:	year 1	each subsequent year	income per year
Plan 2	595,208	505,208	680,000
Plan 3:	643,968	453,968	680,000

		costs	income	profit	profit/year
for 3 years	plan 2	1,605,624	2,040,000	434,376	144,792
	plan 3	1,551,904	2,040,000	488,096	162,698
for 10 years	plan 2	5,142,080	6,800,000	1,657,920	165,792
	plan 3	4,729,680	6,800,000	2,040,320	204,032

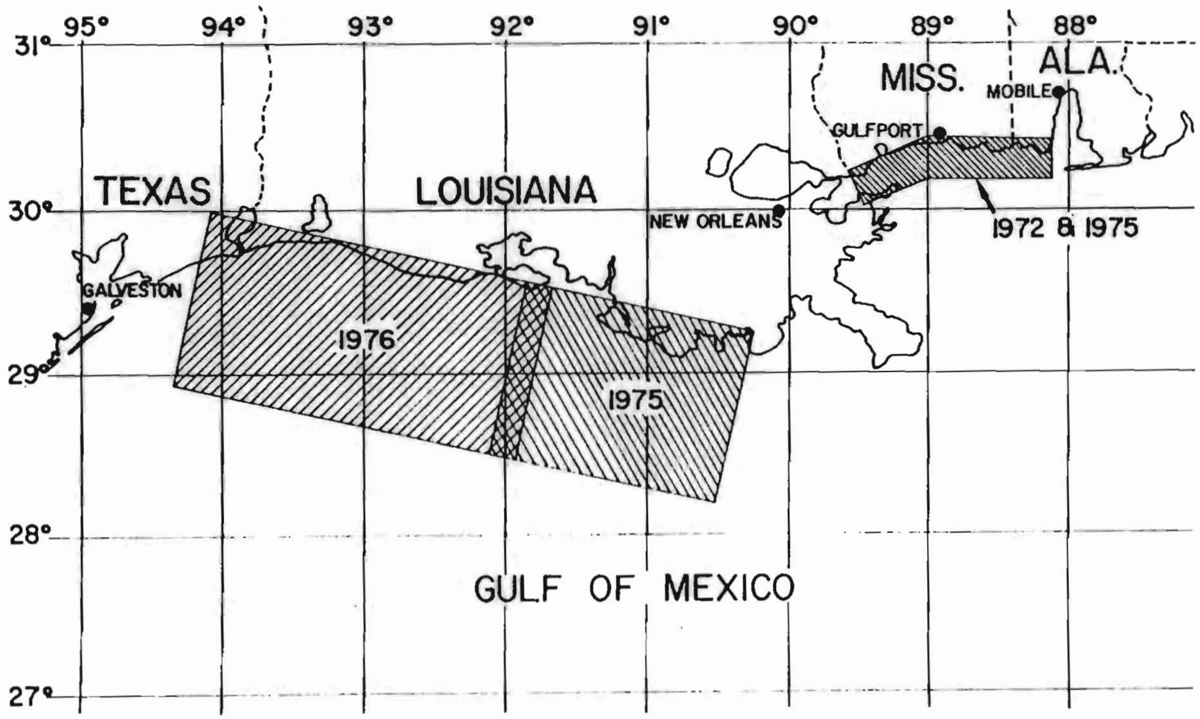


Figure 1. Gulf of Mexico Menhaden study areas, 1972-1976. (From Kemmerer, 1980)

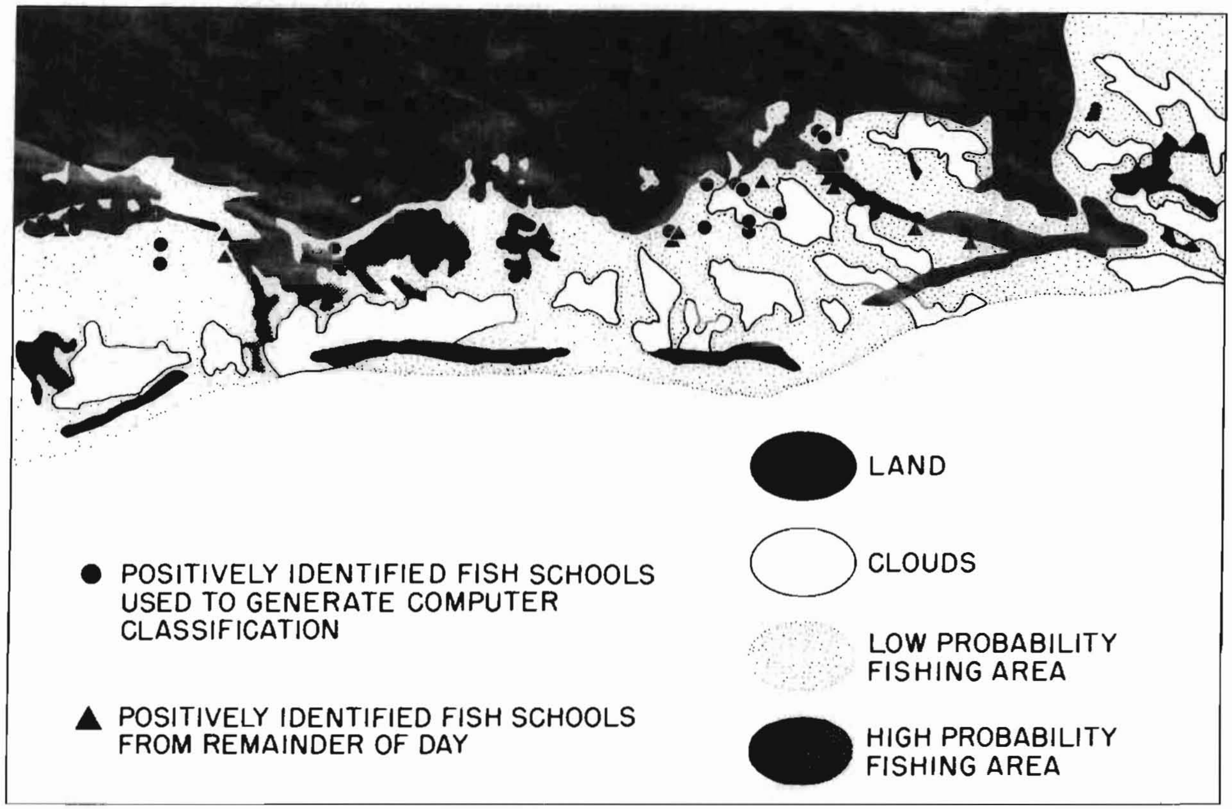


Figure 2. Computer classification of LANDSAT data into high and low probability fishing areas (data from 20 May, 1975). (From Kemmerer and Butler, 1977)

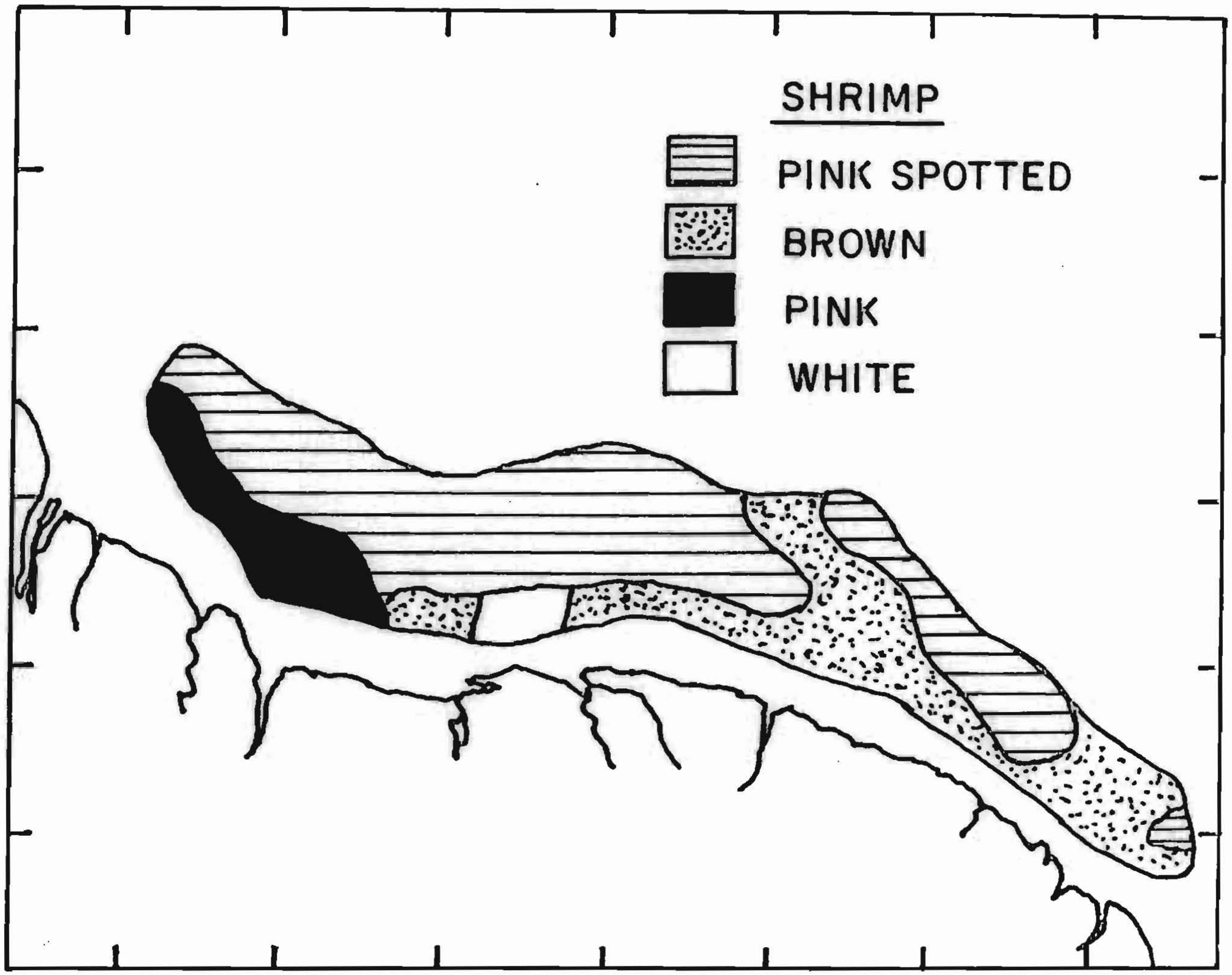


Figure 3. Shrimp distribution patterns off the coast of South America. (From Brucks et al., 1975)

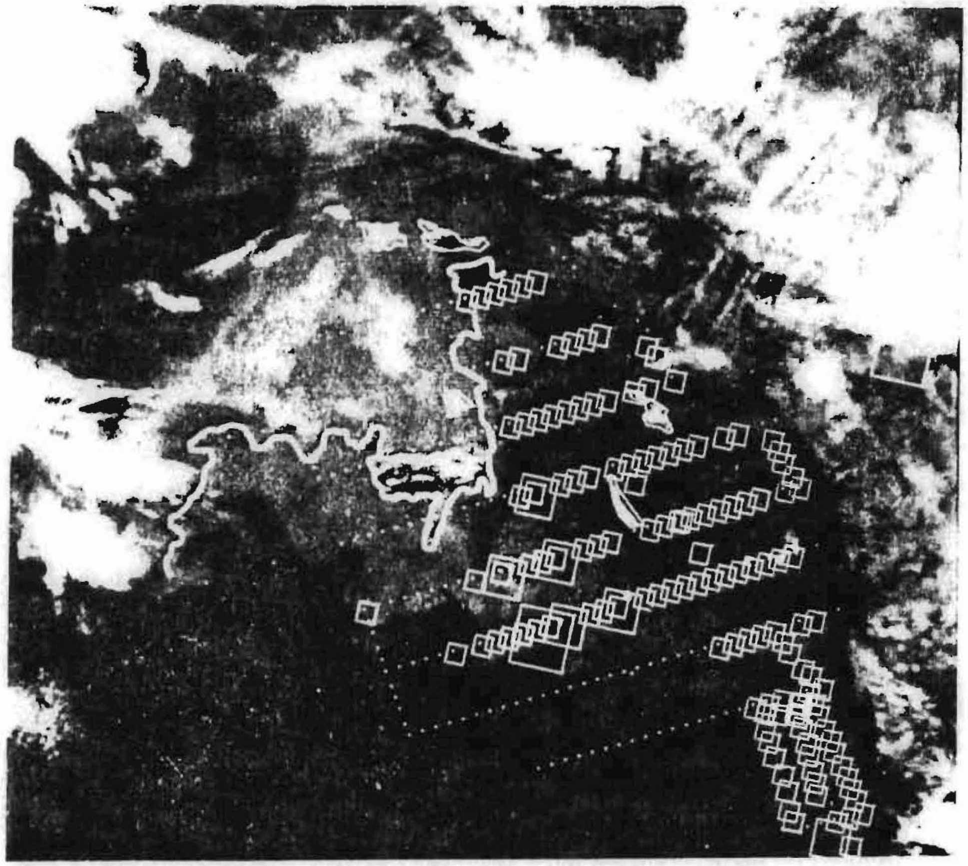


Figure 4. Distribution of Anchovy eggs superimposed on the thermal image of Southern California Bight taken April 6, 1980. The 14°C isotherm plotted from satellite grey-scale calibration has been drawn in. Feathery white objects are clouds. Squares indicate number of anchovy eggs under one square meter of sea surface. (From Lasker et al., 1981)

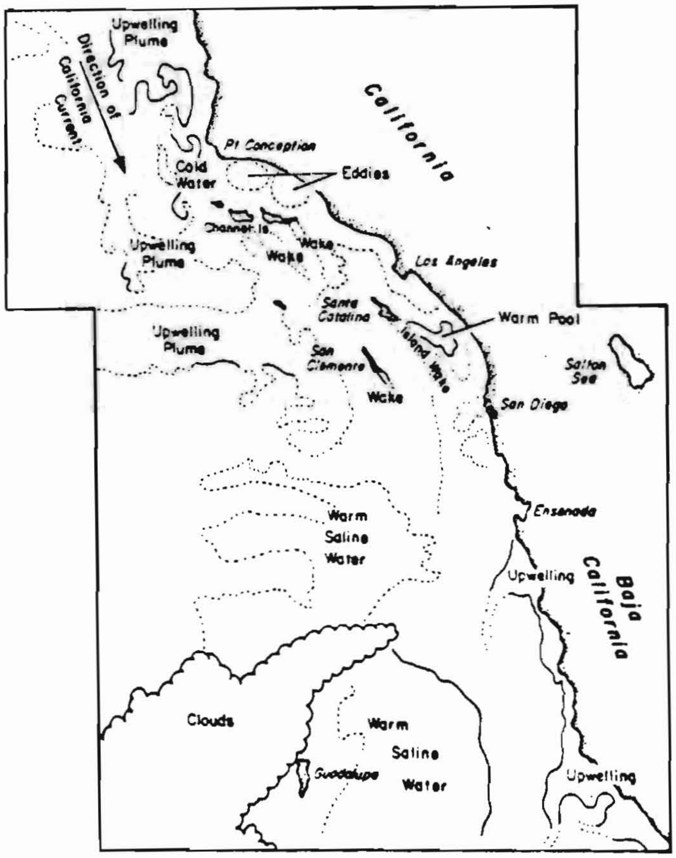


Figure 5. Interpretation of thermal regimes in the Southern California Bight, from March 28, 1980 AVHRR image. (From Lasker et al., 1981)

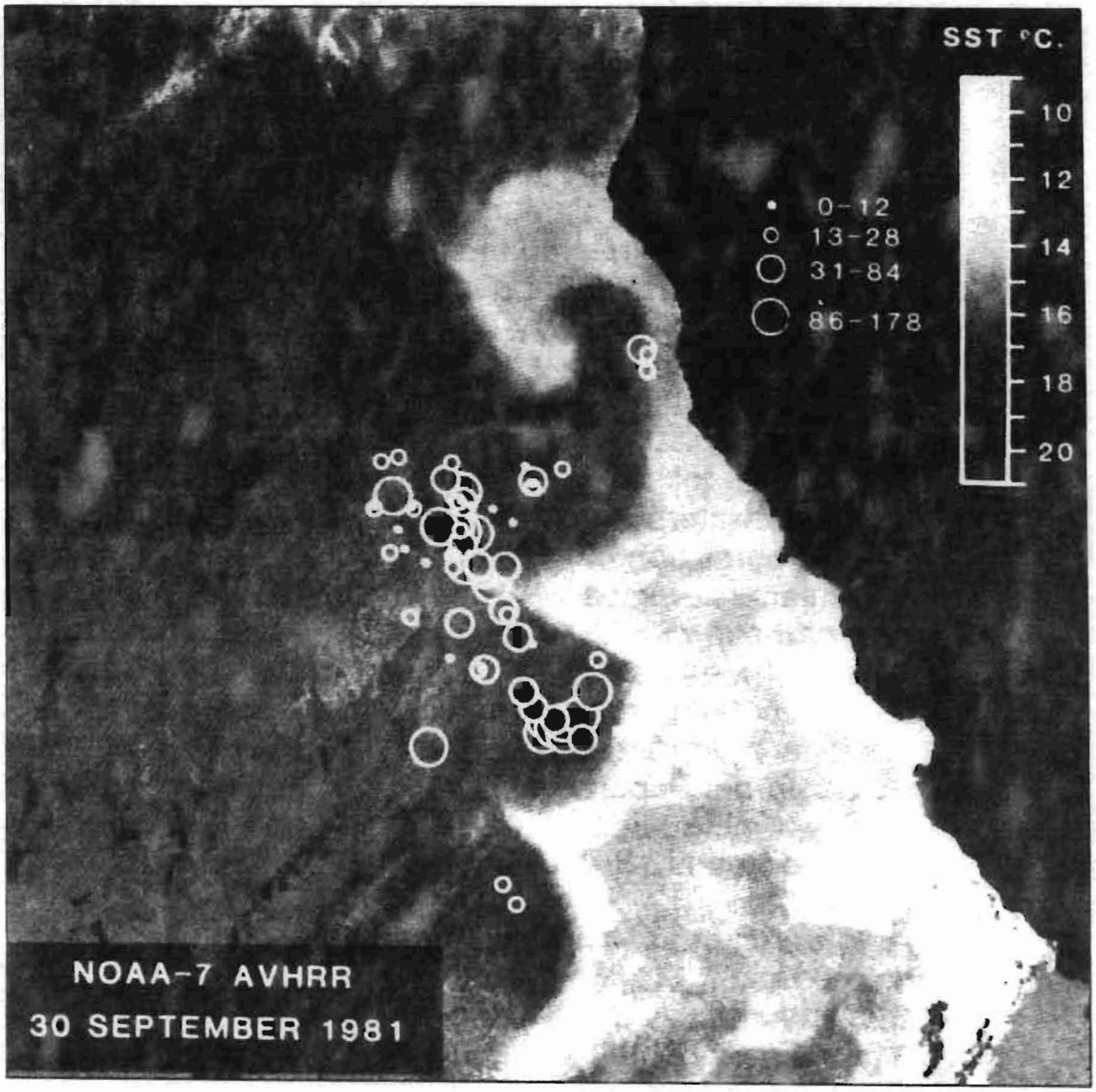


Figure 6. AVHRR thermal image of the Southern California Bight taken September 30, 1981, and superimposed with Albacore catch. Dark areas indicate warm water, light areas indicate cold water. (From Laurs et al., 1984)

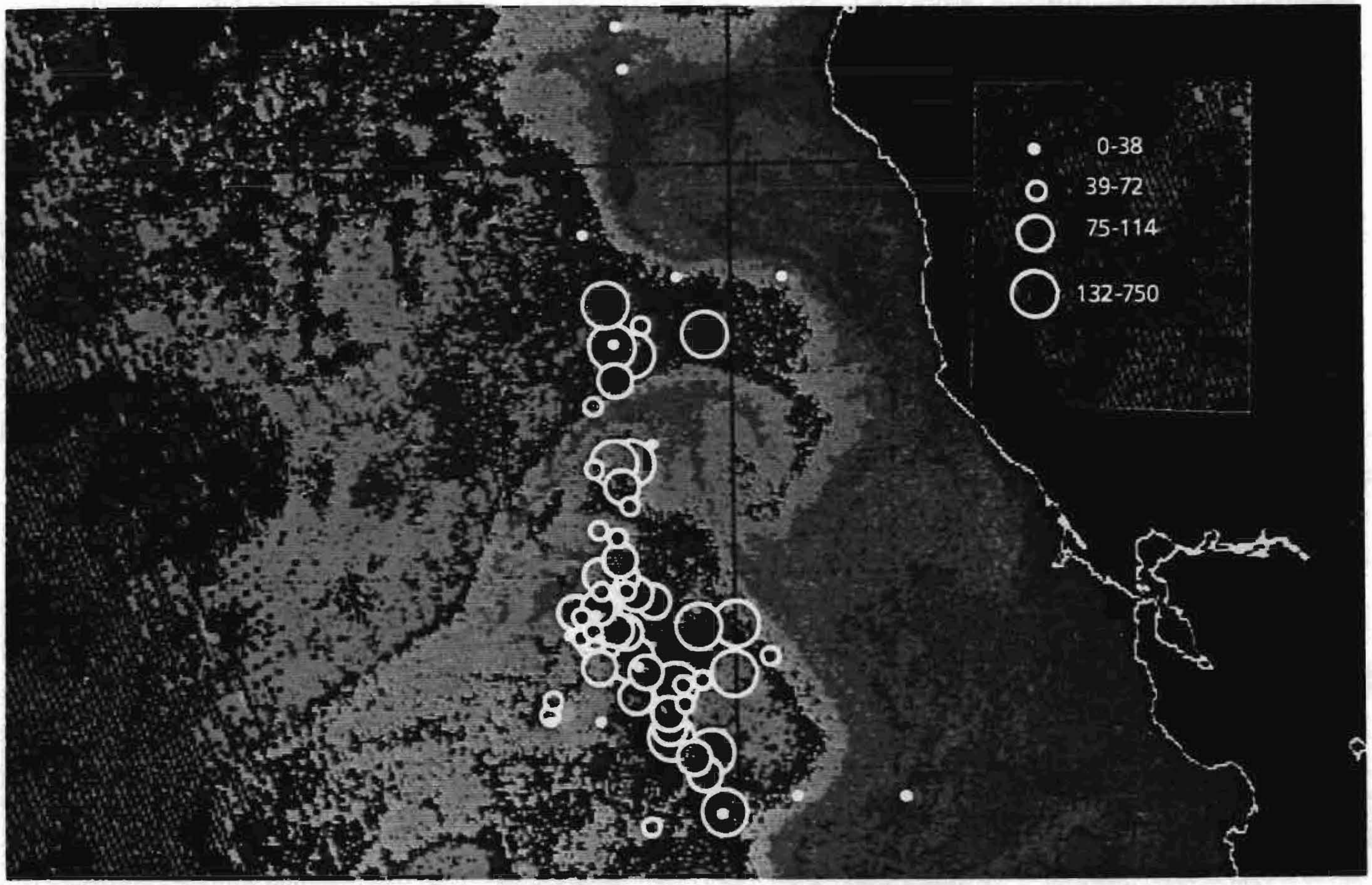


Figure 7. CZCS ocean color image of the Southern California Bight taken September 22, 1981, and superimposed with Albacore catch. The image is false color enhanced; land is masked with black, while clouds appear black, and blue and green areas are more productive than the orange coastal areas. (From Laurs et al., 1984)

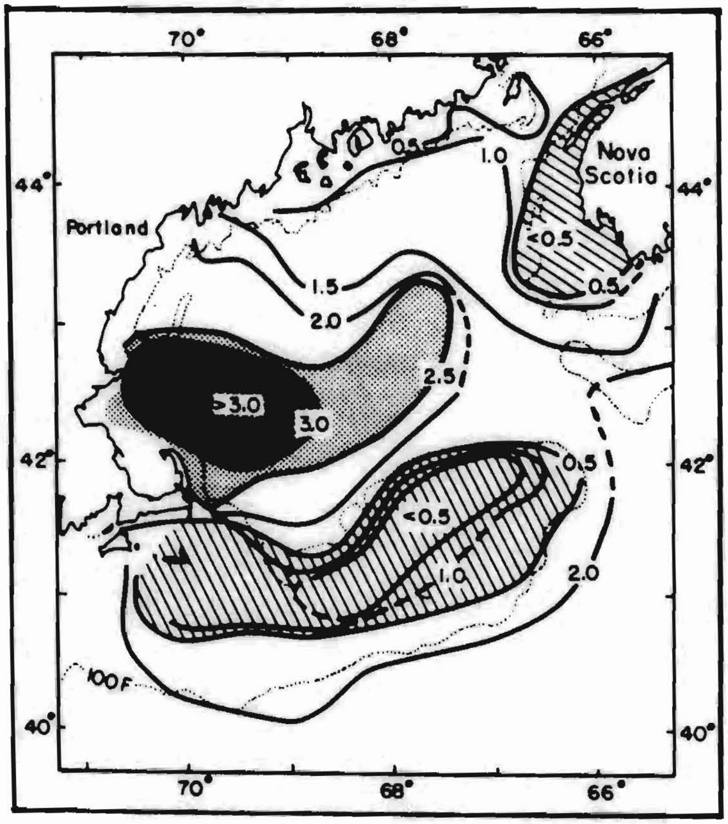


Figure 8. High and low stability areas in the Gulf of Maine, determined by Bigelow, 1928. Dark areas represent stable areas of low productivity; shaded areas are mixed water of high productivity and low stability. Contour lines are sigma-t difference between the surface and a depth of 40 meters. (From Yentsch, 1983)

Figure 9. Gulf of Maine CZCS image from June 14, 1979. Regions of high phytoplankton pigment concentrations are shown in brown, intermediate areas in red, yellow and green, and lowest levels in blue. (Photograph supplied by NASA)

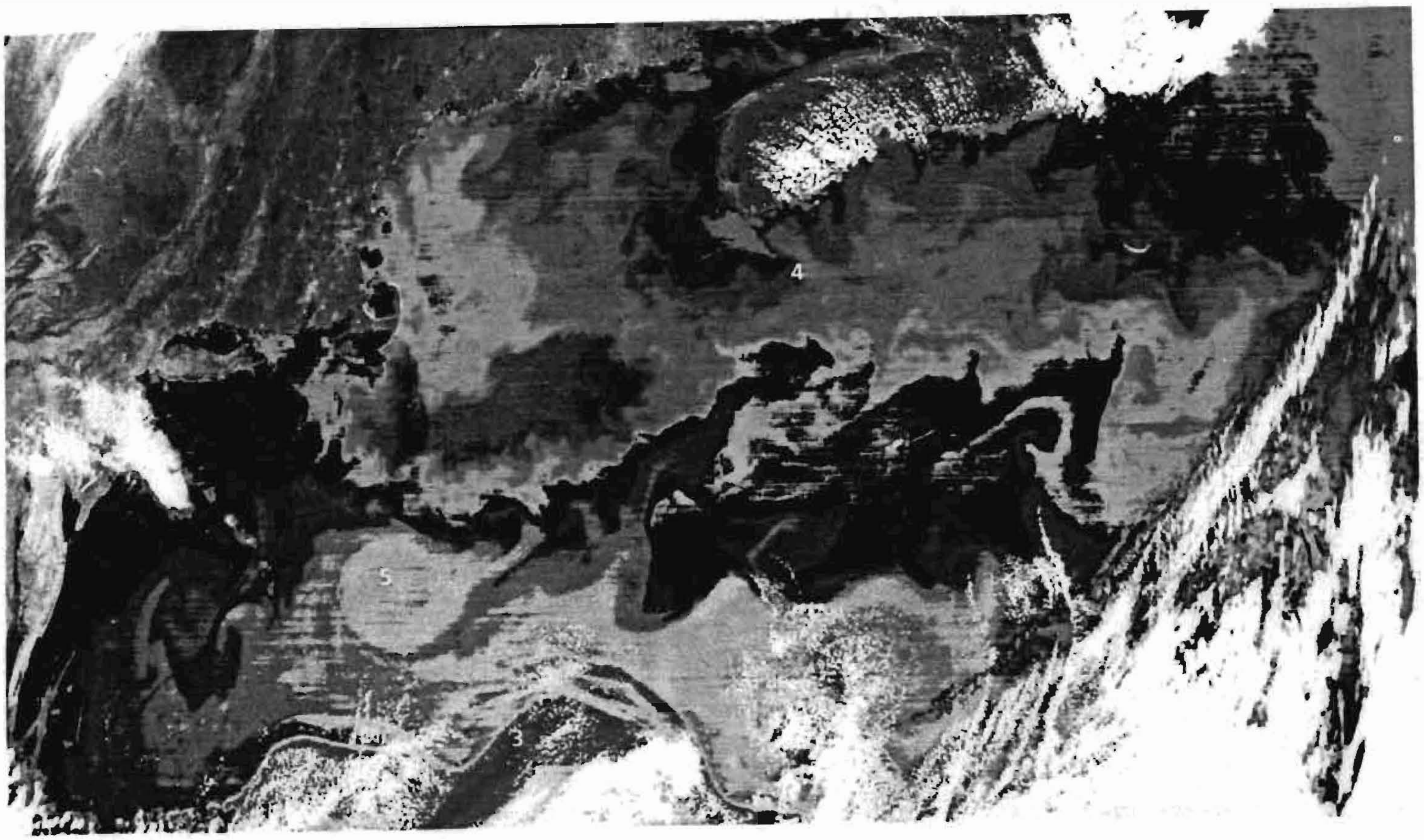


Figure 10. CZCS temperature image of the Gulf of Maine from June 14, 1979. Warm water is color coded in red, cooler waters in yellow and green, and cold water is blue. (Photograph supplied by NASA)

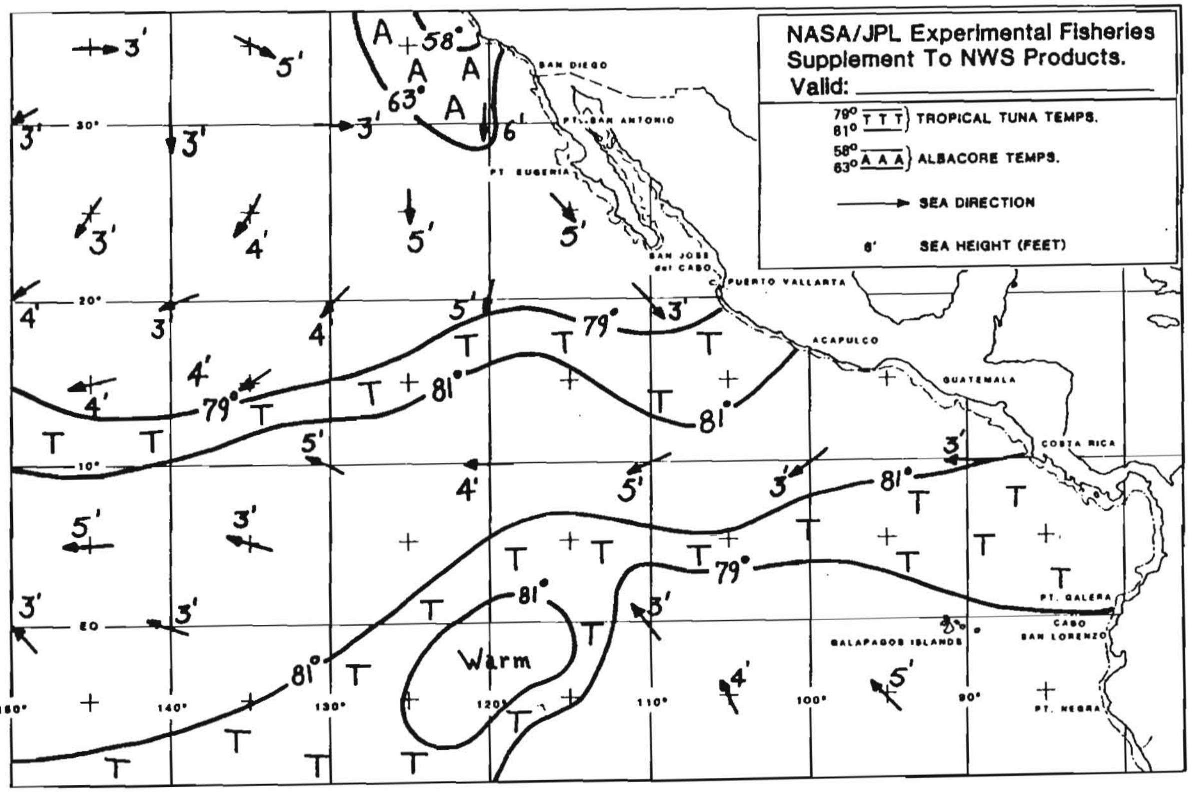


Figure 11. NASA/JPL Experimental Fisheries Aid Chart No. 1. Tropical Area. (From NASA, 1981c)

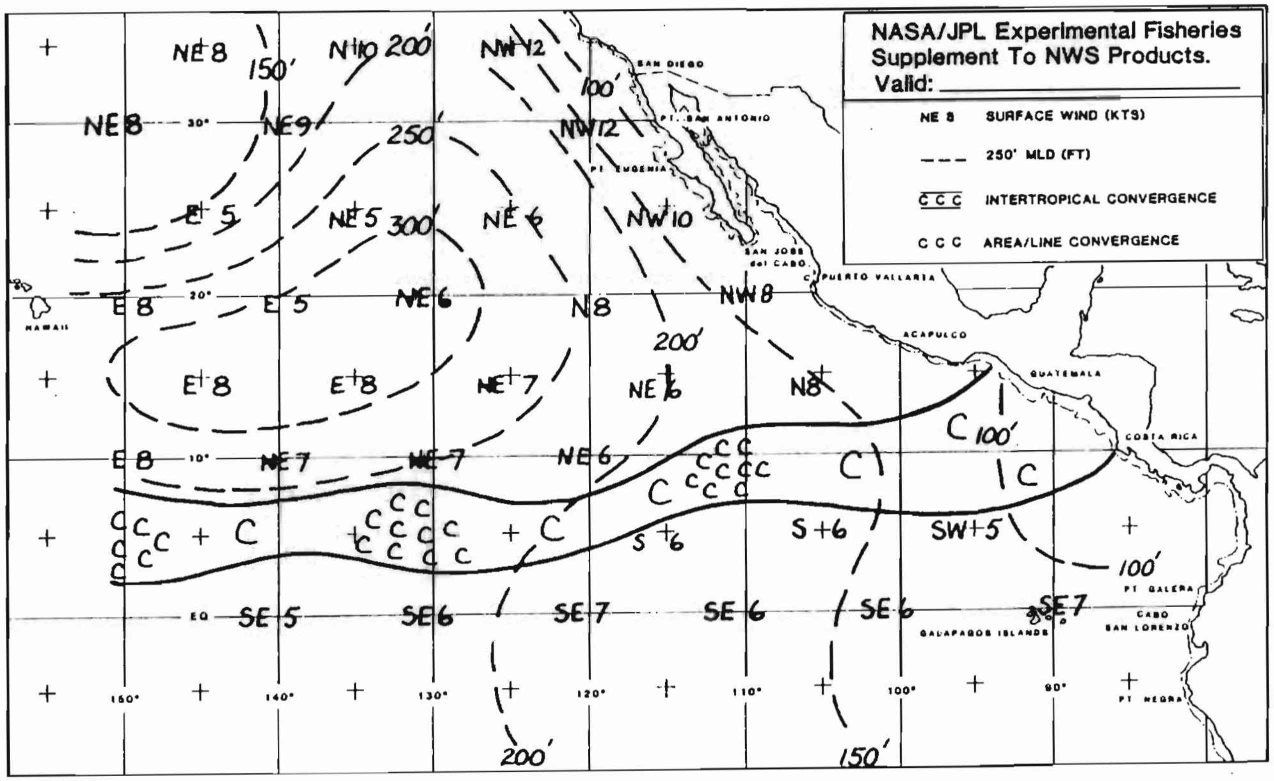


Figure 12. NASA/JPL Experimental Fisheries Aid Chart No. 2. Tropical Area. (From NASA, 1981c)

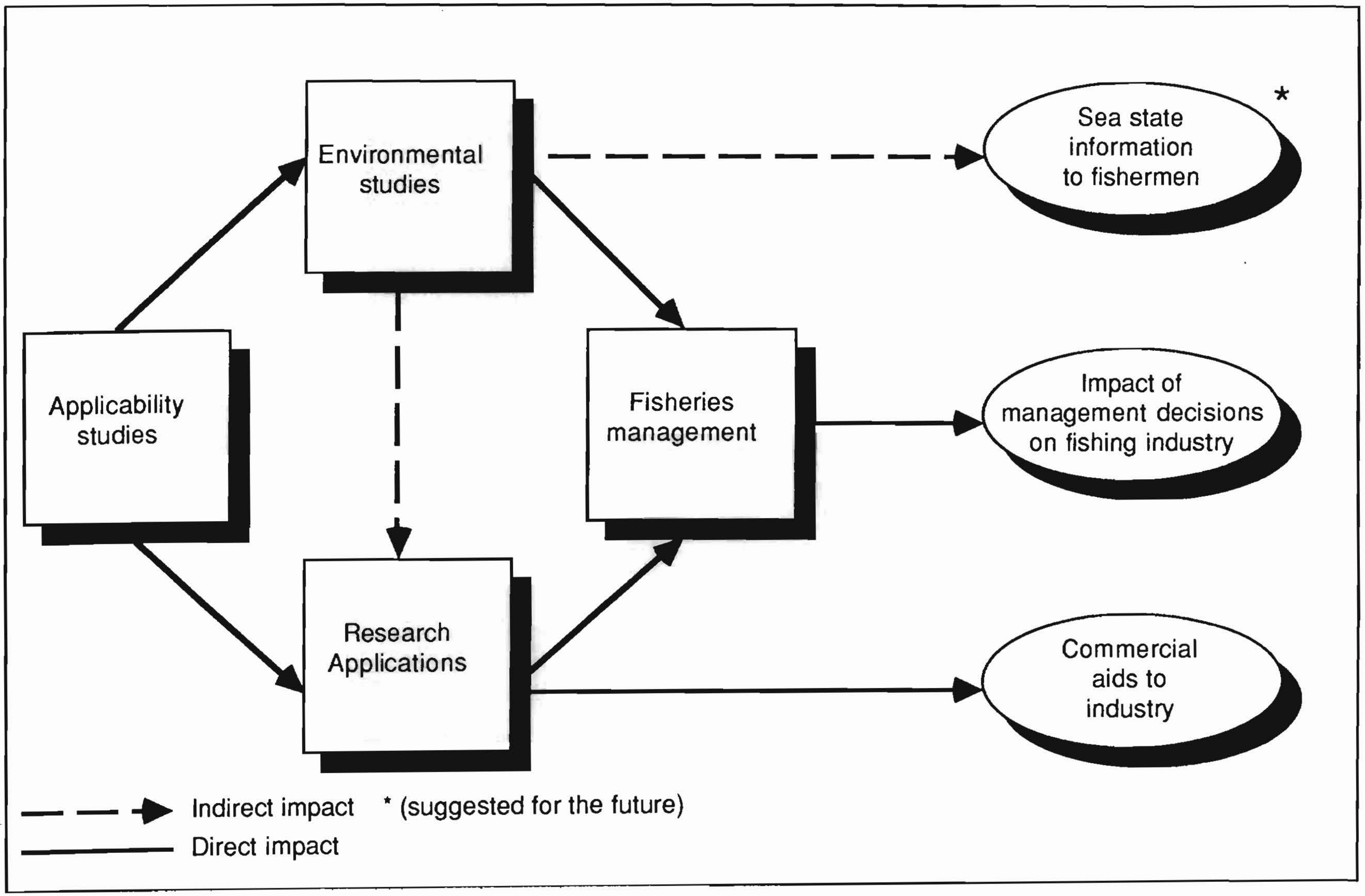


Figure 13. Flow chart for remote sensing and fisheries

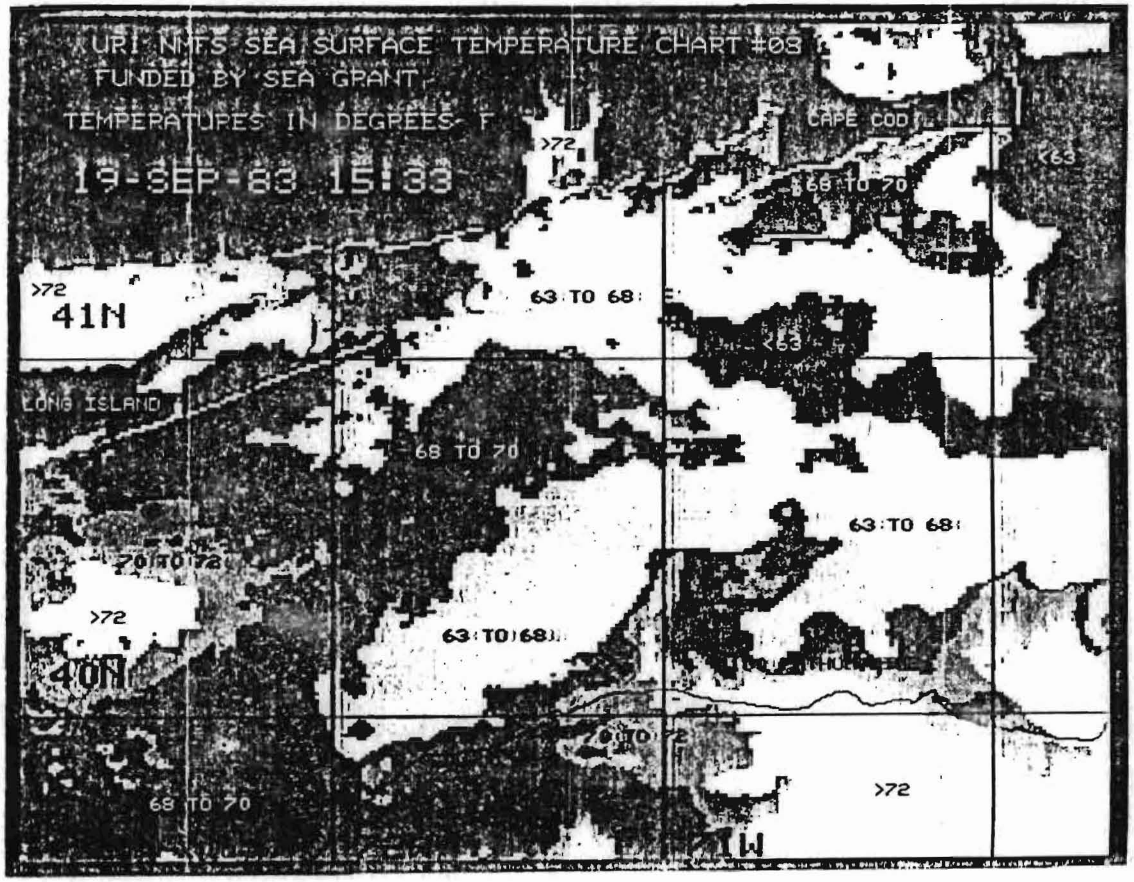


Figure 14. Experimental SST Fisheries Chart URI/NMFS. (Provided by Cornillon)

Sea Surface Temperature Chart Survey

1. Which of the following best describes your interest in SST charts?

    a. commercial fisherman ☐ b. recreational fisherman ☐
    c. charterboat fisherman ☐ d. scientific research ☐
    e. teaching ☐ f. coastal management ☐ g. curiosity ☐
    h. other___________

2. If you use the charts for fishing, have they saved you money in travel time? a. yes ☐ b. no ☐

3. If you answered yes to question 2, please estimate (in dollars) the amount of fuel which you saved by using the SST charts as a reference for highly productive fishing grounds______________.

4. Have the charts helped you to successfully locate fishing grounds with high yields? a. yes ☐ b. no ☐

5. Would you find regional SST charts for other geographic areas useful in your fishing operation? a. yes ☐ b. no ☐

6. If yes, which areas?

    a. Gulf of Maine ☐ b. George's Bank ☐ c. New York Bight ☐
    d. Cape Hatteras ☐ e. other____________.

7. Would you like to receive the charts again next year?

    a. yes ☐ b. no ☐

8. Would you be interested in accessing real-time regional SST charts via radiofacsimile? a. yes ☐ b. no ☐

9. The URI/NMFS trial project for distribution of SST charts has ended. If arrangements cannot be made for the regional SST charts to be made available over radiofascimile next year, URI may consider continuing first-class mail distribution of the charts on a subscription basis. If so, distribution of timely SST charts would be targeted for 2-3 times/week in summer and once/week in winter.

What is the maximum annual subscription fee that you would be willing to pay for next year if we were able to improve the service as described above?

    a. $1/week ☐ b. $5/week ☐ c. $10/week d. $20/week

Figure 15. URI/NMFS Fisheries Questionnaire. (From Hickox)

APPENDIX I

A BRIEF OVERVIEW OF REMOTE SENSING TECHNOLOGY

APPENDIX I

A BRIEF OVERVIEW OF REMOTE SENSING TECHNOLOGY

Data obtained from satellite-borne sensors add important new dimensions to oceanographic (and therefore fisheries) research. Shipboard methods of observation are limited in time and space by the vessel's relatively slow speed. Satellite remote sensing provides extensive geographical coverage, with real time transmission of data, and synopticity far beyond vessel or aircraft capabilities. Repeat coverage allows for comparative analysis over time.

The material for this chapter was derived from Cornillon (1982). The reader is referred to this source for coverage of satellite and sensor design specifications and historical background. This reference manual also includes information on data availability and ordering procedures.

Satellites

Satellites are classified in several ways. The most general category distinguishes between defense and non-defense oriented satellites. Among civilian satellites (data from which are available to the scientific community) classification is with respect to mission type, operational status and orbit type. Mission designations include oceanographic, meteorologic, geologic, and land cover classification. In the United States, civilian satellites are developed and administered by the National Aeronautics and Space Administration (NASA) until they become operational, at which time they are transferred to the authority of the National Oceanographic and Atmospheric Administration (NOAA). Satellite nomenclature can be confusing, with naming conventions determined by the data source. Generally, before launch a satellite is designated by a letter following the series prefix. Upon successful launch a number replaces the letter.

Orbit type is designated as general, encompassing all possible orbits, or geo- or sun-synchronous depending upon the specific nature of these orbits. Sun-synchronous satellites are characterized by near polar orbits at an altitude of approximately 1000 km. These satellites provide good spatial resolution accompanied by a high data rate, and repeat coverage is measured in days. The orbit is referred to as sun-synchronous because the plane of the orbit retains the same orientation with respect to the earth-sun vector; hence at any given location, the point on the earth below is at the same local sun time. This standardization is important for those passive sensors that measure reflected solar radiation and are thus affected by sun angle, but it can result in a biasing of the sampled data especially of biological variables which may also be correlated with the time of day.

Geostationary or geosynchronous satellites are those that orbit the Earth above the Equator at the same rate at which the Earth rotates; hence they remain fixed above the same point on the Earth's surface. One or two geosynchronous satellites provide total coverage of the continental United States. These satellites orbit the Earth at an altitude of approximately 36,000 km. This great distance causes spatial resolution to be coarse, and the resultant data rate is much lower than that of polar orbiting satellites. Repeat coverage is almost continuous.

Non-specific or general orbits are not related in any well defined way to the location of the sun in the sky or to a fixed point on the Earth's surface. Skylab and SEASAT were in such orbits. Skylab was the manned mission in 1973 which evaluated sensors designed specifically for oceanographic research. SEASAT was a "proof of concept" mission and the first satellite dedicated to oceanographic research.

Sensors

Satellite imaging involves physics of a complex nature relating the characteristic properties of electromagnetic radiation to substances dissolved or suspended in the water. The electromagnetic spectrum describes the frequencies or wavelengths of this radiation. Each point of the spectrum corresponds to electromagnetic waves of a well defined wavelength. For convenience, the spectrum is subdivided into bands of similar properties ranging from the ultraviolet (short waves) to the visible, infrared, microwave and radio wavelengths (long waves) (Figure 16). Remote imaging for fisheries and oceanographic science is dependent primarily on the visible, thermal infrared and microwave bands in the following manner: Sensors mounted on Earth-orbiting satellites detect electromagnetic radiation from the surface.

This radiation is emitted from or reflected by the Earth's surface, or originates in the intervening atmosphere. Each wavelength provides information about surface characteristics at a given point. These characteristics create a "spectral signature" which identifies features. For instance, surface waters of $10^{o}C$ emit radiation which peaks at a specific wavelength in the thermal region of the spectrum. The data are recorded in digital form, often processed by computer and displayed on a television monitor, in which all areas of $10^{o}C$ are represented by the same intensity, and temperature patterns can then be identified.

Sensors are electro-optical devices which apply geometric principles to focus incoming radiation onto a dectector which transforms the signal into an electronic signal. The voltage levels are then digitally recorded onto magnetic tape for processing.

Sensors are imaging or non-imaging devices. Imaging sensors provide information that is areal in nature; two dimensional images stressing parameter variability in space. Non-imaging sensors emphasize temporal, spectral or radiometric resolution within the field of view of the sensor.

Sensors are designed to measure specific wavelengths. Generally, sensors that operate within the visible, infrared, and thermal infrared portions of the spectrum are passive sensors. Passive sensors simply record the radiation received from the Earth. Active sensors, usually at microwave frequencies, emit radiation and measurements are based upon the travel time for the signal to reach the Earth's surface and return and the nature of the returning signal. These sensors generate their own energy and therefore have greater power requirements than passive sensors.

Satellite Remote Sensors with Fisheries Applications

This section provides a brief description of some sensors with applications to fisheries and the corresponding satellites (Tables 5,6, and 7). Although these sensors are not the only ones which collect data of interest to fisheries, they are the ones responsible for the data upon which the case studies in this report are based.

Visible, Infrared and Thermal Infrared Sensors

The basic sensors applicable to fisheries operating within the visible, infrared and thermal infrared regions of the electromagnetic spectrum are the radiometer/photometer and the scanner. The radiometer/photometer is a simple, non-imaging sensor, designed to measure a specific wavelength (infrared and above for the radiometer, visible for the photometer) at a given location. Radiometers generally measure radiation in the thermal infrared. Multispectral radiometers measure a number of different wavelengths simultaneously in as many spectral channels. Scanners measure upwelling radiation at a number of locations as the instrument is rotated. Multispectral scanners combine these two concepts measuring a number of wavelengths at a number of locations.

Sensors that measure visible radiation (or light) obtain data on clear, dry days since there is little atmospheric interference on such days. These devices record reflected solar radiation and are therefore inoperable at night. Light penetrates the water column to some extent (blue light to 10-15 meters, red light to approximately three meters). The near infrared portion of the spectrum is useful for imaging vegetation as wavelength characteristics in this region correspond to vegatative reflectance. The atmosphere is easily penetrated by these wavelengths, except during times of heavy cloud cover. Near infrared devices also measure reflected solar radiation. Thermal infrared sensors detect the radiation emitted from the Earth itself; it is therefore possible to collect information during hours of darkness. Thermal infrared radiation does not penentrate cloud cover, and the atmosphere is transparent to these wavelengths only within certain "windows." Outside these windows, thermal infrared radiation is completely absorbed by the atmosphere.

- MultiSpectral Scanner (MSS): LANDSAT

  The MSS was designed to provide repetitive acquisition of high-resolution multi-spectral data of the Earth's surface. The MSS consists of four channels, two in the visible, two in the near infrared. A fifth channel in the thermal infrared was added to later models. The scanner measures visible and infrared signatures of terrestrial, aquatic and nearshore marine regimes. Ground resolution is 79 x 79 meters, but pixel overlap results in an "effective" resolution of 56 x 79 meters. Repeat coverage is 16-18 days for individual satellites. Proper phasing of LANDSAT satellites in orbit results in repeat coverage of 8-9 days.

LANDSAT 1 (initially called Earth Resources Technology Satellite, ERTS 1), launched in 1972, was the first satellite dedicated to measuring earth resources. This sun-synchronous orbiting series has continued through LANDSATs 4 and 5, both with Thematic Mapper instrumentation, and both currently in orbit.

- Coastal Zone Color Scanner (CZCS): NIMBUS 7

The CZCS, with five channels measuring in the visible and one in the thermal infrared, was designed to map chlorophyll content, sediment distribution and surface temperatures of the oceans. Sensor tilt can be adjusted from the ground to avoid sun glint and enable it to "see" into the water column. Local sun time is noon daily so as to enable maximum solar penetration of the water column. Ground resolution is .8 km, and repeat coverage is 24 hours for the visible channels and 12 hours for the thermal channel. Relative accuracy in the thermal band is 0.25^{o}C. The visible channels have been the sensor's greatest asset to date for fisheries related work. As NIMBUS 7 is dedicated to testing many sensors for future applications, the CZCS is activated for only two hours a day in two minute periods to minimize power usage.

NIMBUS 1, launched in 1964, was the first of the research and development polar orbiting meteorological series which has continued through NIMBUS 7.

- Very High Resolution Radiometer (VHRR) : TIROS M series

The VHRR was a two channel (visible and thermal infrared) scanning radiometer mounted on NOAA 2-5 satellites, designed to continuously measure surface temperatures of the earth, sea, and cloud tops in daylight, as well as at night, and to transmit temperature data in real-time to weather stations throughout the world for local weather forecasting.

The VHRR had a resolution of .8 km, repeat coverage of 24 hours for the visible band and 12 hours for the thermal infrared band, and a relative accuracy range of 0.5°C for thermal measurements.

Also known as ITOS 1 (Improved TIROS Operating Satellite), TIROS M was the prototype for the second generation satellites derived from the original TIROS polar orbiting meteorological series. TIROS M was launched in 1970 and incorporated technological advances that resulted from early NIMBUS series research. The first operational satellite of the TIROS M series was launched in 1970 and was named NOAA 1. The series continued through the launch of NOAA 5 in 1976.

- Advanced Very High Resolution Radiometer (AVHRR): TIROS N series

The AVHRR is a four and five channel scanning radiometer designed for day and nighttime measurement of cloud top and sea surface temperature. Channels are in the visible, infrared and thermal infrared. An additional channel in the infrared was added to the later models. Resolution is 1.1 km, with repeat coverage of 24 hours for the visible channels and 12 hours for the thermal infrared channels. Relative temperature measurements are accurate to 0.2°C.

The TIROS N series of third generation polar orbiting meteorological satellites was initiated with the launch of the prototype TIROS N in 1978. The series was continued with NOAA 6-9. NOAA 6 and 9 are currently operational.

- Visible Infrared Spin Scan Radiometer (VISSR): ATS/SMS/GOES series The VISSR includes a set of eight radiometers in the visible portion of the spectrum and one thermal infrared channel, and is mounted on the SMS/GOES series. The VISSR provides day and night observations of Earth/cloud radiance temperature measurements in order to map weather circulation features. The resolution is 0.78 x 0.78 km for the visible channels and 7 km at nadir for the thermal infrared channel. Repeat coverage is 30 minutes for the earth disc measured by the sensor, but can be adjusted to obtain an image covering a segment of the full disk every 15 minutes. It is the VISSR thermal infrared data that has been useful in obtaining information relevant to fisheries.

The ATS/SMS/GOES series of geostationary meteorological satellites was initiated with the launch of ATS 1 (Applications Technology Satellite) in 1966, as a research and development satellite. SMS 1

(Synchronous Meteorological Satellite) was launched in 1974 as a prototype for the operational geosynchronous satellites. SMS 3, renamed GOES 1 (Geosynchronous Operational Environmental Satellite), was launched in 1975. Since then, two GOES satellites have provided coverage of the continental United States, until recently when GOES 5, the sole remaining operational satellite in the series was positioned midway between the two coasts. The VISSR Atmospheric Sounder (VAS), an improved version of the VISSR has flown on GOES satellites since 1980. These satellites provide the images seen on local television weather reports.

Microwave Sensors

Microwave radiation will penetrate clouds with minimal reduction in the strength of the signal, and can be used in all weather conditions, except for very heavy rains. Active microwave sensors irradiate the Earth's surface and then measure the characteristics of the reflected signal which is in general stronger than that at the same frequency resulting from reflected solar radiation or radiation emitted by the Earth's surface. Microwave wavelengths (including radar in the upper range) provide valuable information on surface irregularities as the wavelengths correspond to small surface features (i.e., grains of sand, capillary waves).

- The SEASAT A Scatterometer (SASS) is the microwave sensor which has been used by fisheries researchers to provide information on wind stress at the oceans' surface. A scatterometer is an active, non-imaging sensor designed to measure wind stress, magnitude and direction. The SASS was composed of four antennae which measured from different angles the reflected signal from capillary waves at a single point on the surface. Resolution of the sensor was 50 km and repeat coverage was at least every 36 hours. This radar system operated in the 14.595 GHz range.

SEASAT A was launched in 1978 but the mission ended prematurely after only 99 days, due to a power failure on the satellite.

SATELLITE	ORBIT TYPE	SATELLITE TYPE	ORBIT ALTITUDE	ORBIT PERIOD	ORBITS / DAY	SENSOR
NIMBUS 7	sun-synchronous	R and D meterology	955 km	110 min	13.1	CZCS
TIROS M (NOAA 2-5)	sun-synchronous	Operational meterology	1450 km	116 min	12.4	VHRR
LANDSAT	sun-synchronous	Earth resources	912 km	LANDSAT 3: 103 min LANDSAT 4: 99 min	14.0 14.6	MSS
TIROS N (NOAA 6-9)	sun-synchronous	Meterology	850 km	102 min	14.25	AVHRR
GOES	geo-synchronous	Meterology	35,800 km	24 hrs	1	VISSR
SEASAT	general	Oceanography	800 km	100.8 min	14	SASS

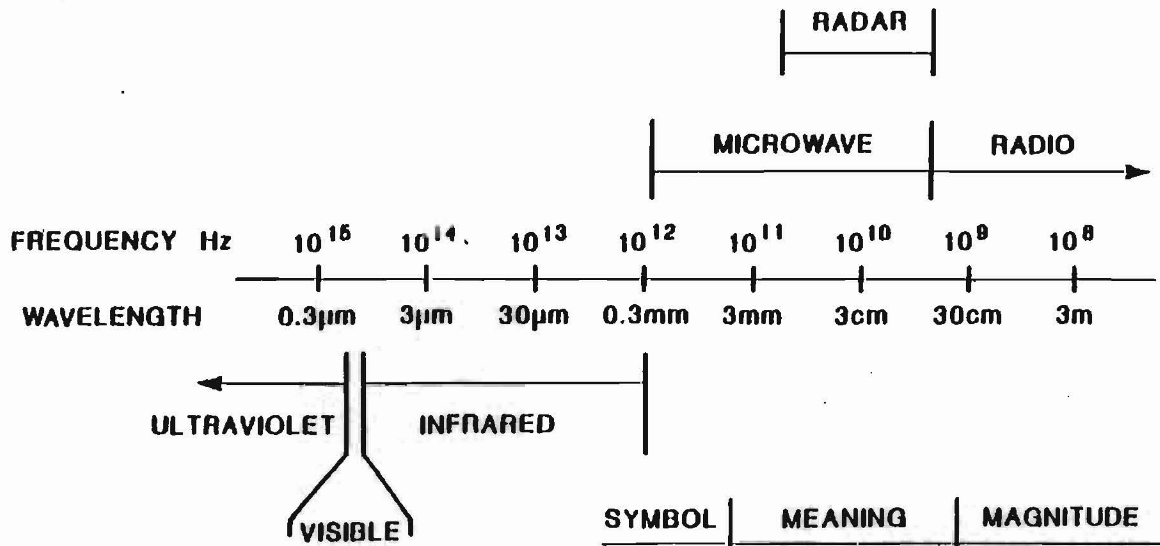
Table 5. Satellite characteristics

SENSOR	RESOLUTION	REPEAT COVERAGE	ACTIVE-PASSIVE	SENSOR TYPE	CHANNELS	PARAMETERS	SATELLITE
CZCS	.825 km	visible: 24 hr	passive	Scanning radiometer	5 visible 1 thermal	color temperature	NIMBUS 7
VHRR	visible: .8 km infrared: .8 km	visible: 24 hr infrared: 12 hr	passive	Scanning radiometer	1 visible 1 thermal	cloud cover temperature	TIROS M NOAA 2 - 5
MSS	55 x 79 m	16 - 18 days	passive	Scanning radiometer	2 visible 2 near infrafred 2 thermal	color temperature	LANDSAT 1-5
AVHRR	1.1 km	visible: 24 hr infrared: 12 hr	passive	Scanning radiometer	2 visible 2 near infrared 2 thermal	cloud cover temperature	TIROS N NOAA 6-9
VISSR	visible: .78x.78 km thermal: 7 km	30 min	passive	Scanning radiometer	1 visible 1 thermal	weather features temperature	GOES 1 - 4
SASS	50 km	36 hr	active	Scatterometer	microwave 14.595 Ghz	surface wind stress	SEASAT

Table 6. Comparison of sensor characteristics.

SENSOR	CHANNEL	WAVELENGTH (μm)	
CZCS	1	.433 - .453	blue
	2	.510 - .530	green
	3	.540 - .560	yellow
	4	.660 - .680	red
	5	.700 - .800	far red
	6	10.5 - 12.5	thermal infrared
VHRR	1	.6 - .7	visible
	2	10.5 - 11.5	thermal infrared
MSS	1	.5 - .6	visible
	2	.6 - .7	visible
	3	.7 - .8	visible
	4	.8 - 1.1	near infrared
(LANDSAT 3 only)	5	10.4 - 12.6	thermal infrared
AVHRR	1	.55 - .9	visible
	2	.725 - 1.1	near infrared
	3	3.55 - 3.93	infrared
	4	10.5 - 11.5	thermal infrared
	5	10.5 - 11.5	thermal infrared
		11.5 - 12.5 (NOAA-7 on)	thermal infrared
VISSR	1	.55 - .70	visible
	2	10.5 - 12.6	thermal infrared

Table 7. Sensor characteristics.



SYMBOL	MEANING	MAGNITUDE
μm	MICROMETERS	10^{-6} METERS
mm	MILLIMETERS	10^{-3} METERS
cm	CENTIMETERS	10^{-2} METERS
Hz	HERTZ or CYCLES/SEC.	

Figure 16. Electromagnetic Spectrum. (From Cornillon, 1982)

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ACRONYMS

ATS	Applications Technology Satellite
AVHRR	Advanced Very High Resolution Radiometer
CZCS	Coastal Zone Color Scanner
EOS	Earth Observing System
ERS	ESA Remote Sensing Satellite
ERTS	Earth Resources Technology Satellite
ESA	European Space Agency
FAO	Food and Agriculture Organization (United Nations)
GOES	Geosynchronous Operational Environmental Satellite
ITOS	Improved TIROS Operating System
JOI	Joint Oceanographic Institutions, Inc.
LAMPEX	Large Area Marine Productivity-Pollution Experiments Program
MODIS	Moderate Resolution Imaging Spectrometer
MSS	MultiSpectral Scanner
NASA	National Aeronautics and Space Administration
NESS	National Earth Satellite System
NFMOA	National Fish Meal and Oil Association
NMFS	National Marine Fisheries Service
NOAA	National Oceanographic and Atmospheric Administration
NROSS	Navy Remote Ocean Sensing System
NSCAT	NASA Scatterometer
OCI	Ocean Color Imager
SFSS	Satellite Field Services Station
SASS	SEASAT-A Scatterometer
SMS	Synchronous Meteorological Satellite
SST	Sea Surface Temperature
TOPEX	The Ocean Topography Experiment
VAS	VISSR Atmospheric Sounder
VHRR	Very High Resolution Radiometer
VISSR	Visible Infrared Spin Scan Radiometer