

# OBSERVATIONS ON REMOTE SENSING IN FISHERIES

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The application of aircraft or satellite remote-sensing systems to the problems confronting the fishing nations of the world is undergoing intensive development. Strangely enough, the evolution of sensing systems to acquire information about the ocean surfaces has outrun our understanding of the basic processes involved in fisheries identification, utilization, or management. This is due to rapid expansion of remote-sensing technical capabilities of several countries over the past ten years.

In looking for ways to utilize this advanced technology to benefit mankind, some very broad assumptions have been made, particularly in the application of remote-sensing technology to fisheries. These assumptions include: (a) direct application of satellite-acquired data to fishing operations; (b) direct use of oceanographic information by fishermen in their daily activities; and (c) the cause-effect relationships between the ocean environment and fish stocks are understood to the point of technical application. These assumptions were made by dedicated technical people who recognized a need to resolve the pressing world fishery problems. Unfortunately, few of these people are able to identify the cause-effect relationship of the fishery problems.

This developing technology of remote-sensing instrumentation from aircraft and satellites, as well as advanced communications and automatic data-handling techniques, are providing unique and exciting opportunities to obtain ocean information so rapidly that they were not comprehensible ten years ago. The challenge is to convert this mass of data to information which can be applied to fishery problems. This article identifies the areas requiring multidiscipline development of fisheries and the environment of fish.

## Rational Resource Use Needed

Effective utilization of living marine resources depends on man's understanding of these resources under natural conditions. There is evidence that the world's capability to harvest living marine resources is approaching a point of diminishing returns. The effects of man as hunter and harvester of fishery resources and polluter of the resource environment are reaching a point where it is necessary for all nations to accept responsibility for rational resource management. Rational use depends on the location and identification of the fish stocks themselves--and of those ecological processes which the stocks rely upon for their food and survival.

As is true on land, the optimum use of the body of water by a living resource depends on the productivity of its environment. Over the years, expansion of knowledge about this environment has been significantly constrained by our inability to study the large-scale environmental phenomena taking place under dynamic conditions. Our present understanding of oceanic processes is based upon slow, scattered survey techniques, limited by man's ability to operate effectively on the ocean. This does not suggest that past efforts have not been significant. On the contrary, it suggests a phenomenal capability of extremely talented individuals to operate under adverse conditions and produce information of profound magnitude. A potential breakthrough in our ability to observe and record ocean-surface phenomena--and thereby revolutionize our understanding of living marine resources--can be identified in the numerous current resource-detecting efforts of several countries. Several efforts in the United States will illustrate the kind of research going on in at least nine other countries.

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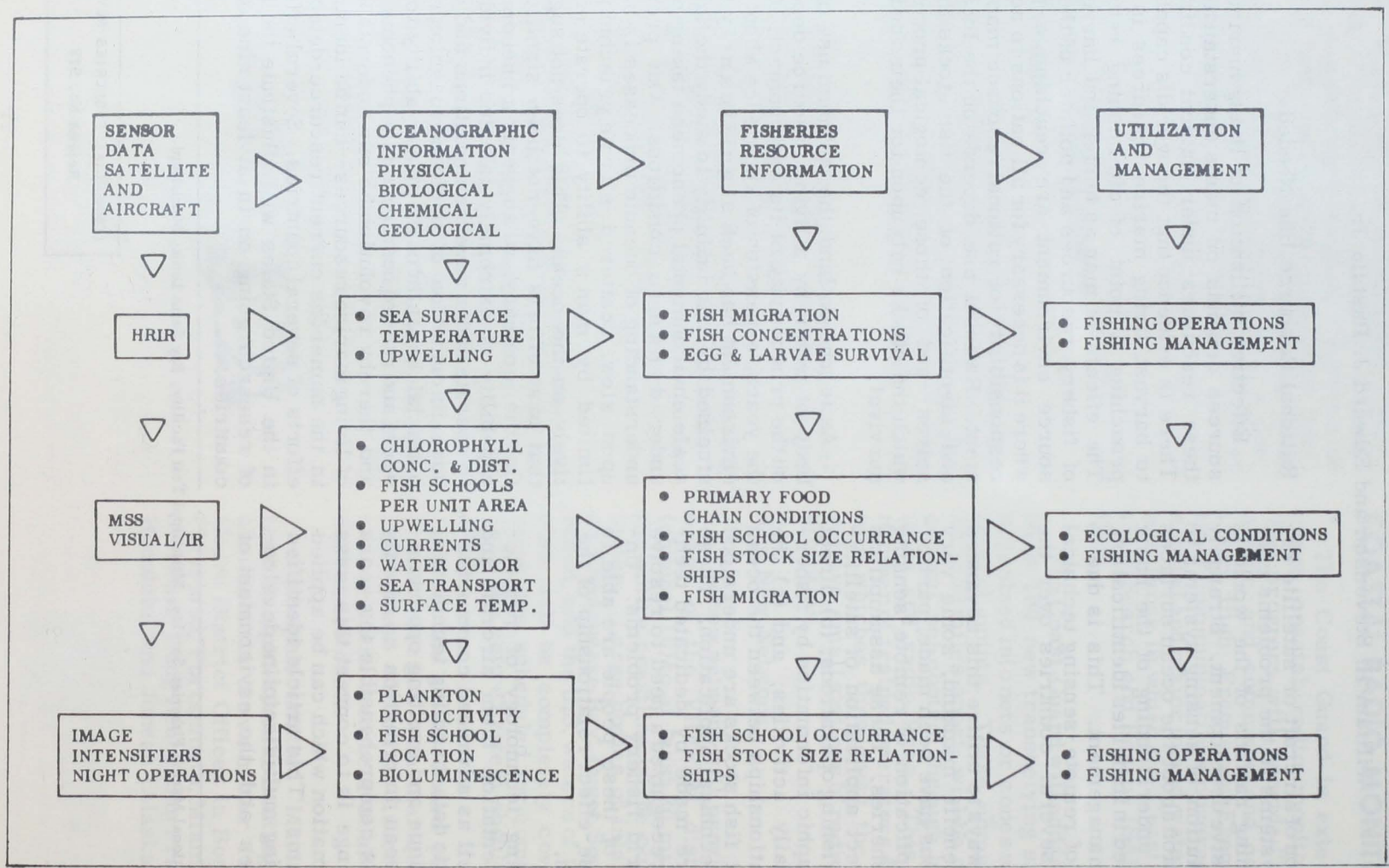


Fig. 1 - Application of Sensor Data to Fishery Utilization.

## Who Can Apply Data?

Direct application of remote-sensing data to the problems of the fisherman in a dugout canoe is not practical (Figure 1). Data from remote-sensing system must be converted into oceanographic information which, in turn, must be integrated with extensive biological data to understand the status of the living marine resource with respect to its environment. Continued use of this resource will, in turn, depend on man's ability to effectively understand and manage the resource stocks within their natural environment. In the United States, the lead agency for developing this expertise and for integrating remote-sensing data with fishery applications, is the National Oceanic and Atmospheric Administration (NOAA) formed in October 1970. NOAA is concerned with resource exploration, development, management, and conservation in the oceans. It is also concerned with environmental monitoring, prediction, and modification, including living marine resources, and with developing the capacity to exercise, ultimately, some degree of environmental control. Here, environment means the oceans, the atmosphere, and solid earth. We are concerned with developing the science and technology required to execute these tasks.

## CURRENT ACTIVITIES

### SATELLITE AND AIRBORNE SENSORS

The present state-of-the-art of remotely sensing oceanographic and related factors from satellites and aircraft platforms has provided tools to view synoptically our natural resources on a scale not thought possible a short time ago. Within the last decade, a variety of sensor-mounted spacecraft and aircraft, both manned and unmanned, have provided oceanographic data on the following factors:

1. Water color (Gemini, Apollo, aircraft)
2. Sea state (aircraft)
3. Surface winds (aircraft)
4. Sea-surface temperature (Nimbus, ITOS, aircraft)
5. Chlorophyll (aircraft)

6. Surface currents (Nimbus, Gemini, Apollo, aircraft)
7. Sediment transport (Apollo, aircraft)
8. Surface salinity (mainly theoretical studies with limited experimentation from aircraft)

Sensor systems aboard the unmanned ERTS-A (Earth Resources Technology Satellite, and the manned Skylab/EREP (Earth Resources Experiment Package) satellites, to be flown in 1972 and 1973, will provide thermal and visual imagery applicable to oceanography. The mission of ERTS-A, to be followed by ERTS-B in 1972, is the repetitive acquisition of high resolution multi-spectral data of the earth's surface. The ERTS-A satellite will carry two sensor systems, one a four-channel multispectral scanner (MSS), and a three-camera Return Beam Vidicon (RBV). A five-channel MSS is programmed for ERTS-B. Technical details of the sensing systems, orbital plan, and operational characteristics are covered by literature available from NASA.

Even though ERTS-A and B, Skylab, and the ITOS series of satellites are not oceanographic-data oriented, the information acquired by their respective sensor systems will be applicable to initiating investigations of living marine resources. Future satellites, such as the unmanned ERTS-E and F, are expected to carry sensor packages and be programmed for specific oceanographic investigations as one of their primary functions. In this regard, the oceanographic and fishery communities have a responsibility to provide input requirements and to keep abreast of remote-sensing techniques and developments, whether the platforms be satellites or aircraft.

### OCEANOGRAPHIC INFORMATION

To date, interpretation of satellite-generated visual and thermal imagery products are of a magnitude lending themselves to large-scale, gross oceanographic and meteorological phenomena which may be related to fisheries. The satellite-acquired data have been used to delineate upwelling areas, major current demarcations, sediment transport, and other large-scale surface features. Scrutinization of these features can be further explored with the aid of aircraft serving as

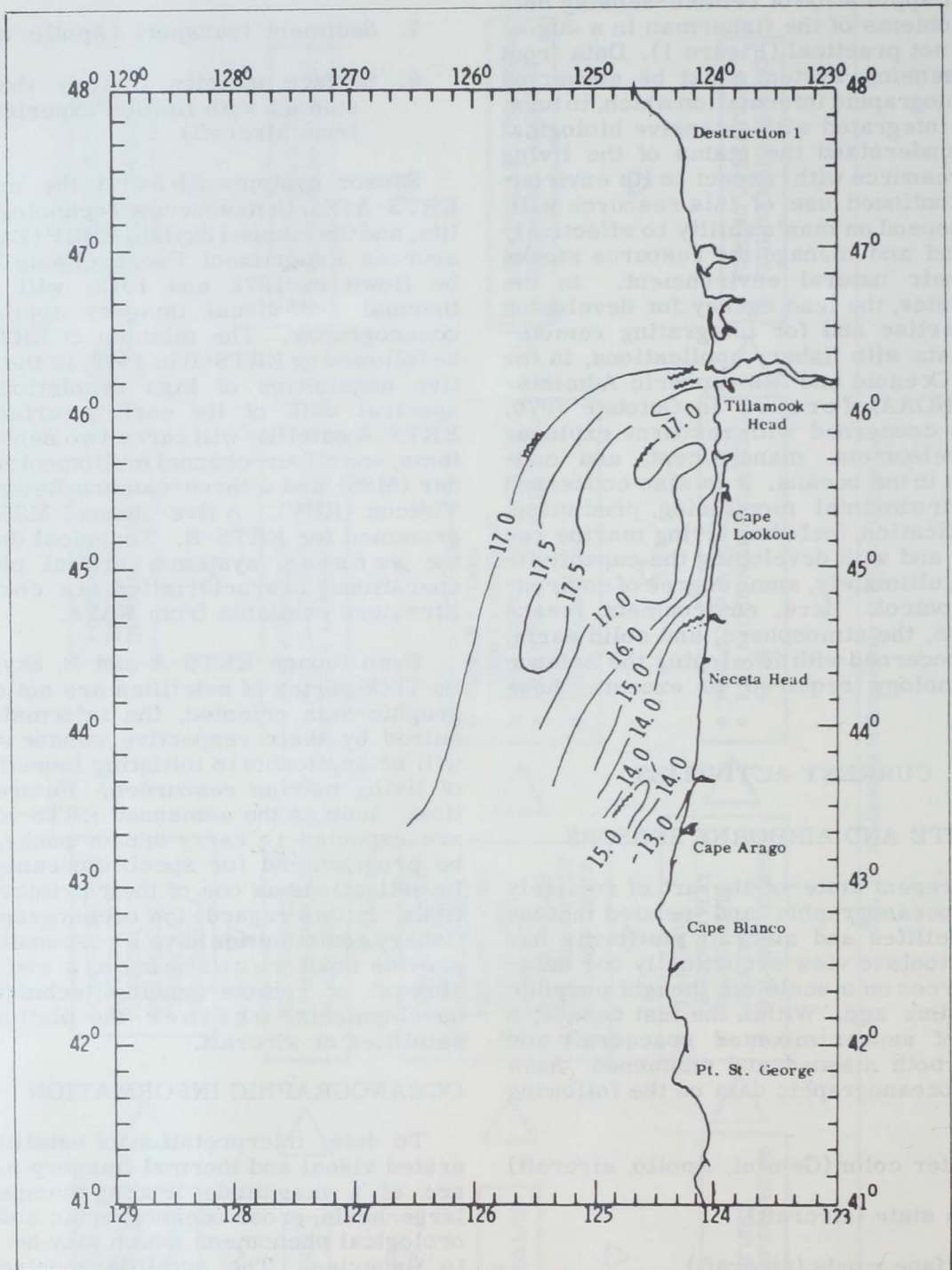


Fig. 2 - Sea-Surface Temperature off Oregon Coast (July 13, 1969) from Airborne PRT-5 Radiometer.

platforms for remote-sensing devices. The aircraft-acquired data, providing they are real time and convertible to fishery information, can become operational information for fishermen's use. Conceivably, these data may provide characteristics of, and relate to, the distribution and abundance of living marine resources.

This overly simplified sequence of events culminating in usable information may appear to be an ideal system for fishery development and utilization--but ideal systems are often plagued with problems when tested. Two primary problems must be resolved satisfactorily before any assessment, monitoring, and prediction program can become an efficient reality:

1. Agreement of the satellite and/or aircraft-acquired data with conventional oceanographic and biological sampling results, and
2. establishment of the relationship of environmental factors to living marine resources.

At present, the problems relating to data agreement are being investigated by a few fishery researchers. They are doing this primarily through conventional acquisition of ground-truth information, and by correlating these data with satellite/aircraft-acquired information obtained via remote-sensing devices. The process of correlating data from the two major modes of acquisition is costly and time consuming, but it is necessary to develop reliable and comparable airborne and satellite sensor systems. Those sensor systems applicable to fisheries are capable of scrutinizing only sea-surface phenomena with any degree of clarity, and subsurface features to an even lesser degree. However, we expect to be able to observe some resource information down to 100 meters in the next 5 to 10 years.

The second problem, relationships between living marine resource and the environmental factors affecting it, is even less understood. To provide the means for utilizing the resource effectively, we must also provide for an effective understanding of the complex relationship between living marine resource and its total environment.

Information applicable to the solution of these problems is being supplied by a few

researchers investigating related oceanographic and biological phenomena. The factors and indicators of current interest are temperature, chlorophyll (color), sediment transport, and salinity. Other factors of importance, but receiving less concentrated attention, are surface and subsurface currents, oxygen concentration, sea state, and delineation of subsurface coastal features.

The measurement of sea-surface temperature has received most attention in sensing with satellite and airborne instrumentation. This study was given impetus by the results attained with meteorological sensing systems, primarily infrared radiometers designed for cloud studies. Thermal sensors were used and discussed by Pearcy and Mueller (1969) in a study suggesting a predictable relationship between temperature and albacore activities in Oregon waters. Figure 2, from their report, is an example of sea-surface temperature derived with the use of an airborne radiometer. A similar investigation conducted a year later, under similar conditions, did not support the original results, and Pearcy (1971) cited complex and rapidly changing sea-surface temperature patterns as a reason for the disparity. Additional research and mapping thermal variations of sea-surface temperature by remote-sensing devices are reported by Smith, et al. (1970).

Through the study of visible and infrared color photographic imagery taken aboard aircraft, Gemini, and Apollo flights, Clarke, et al. (1970) and Ewing (1971) explored the remote-sensing aspects of ocean color as an indicator of biological productivity. They analyzed the spectrum range of backscattered sunlight (Figure 3) from sea-surface areas rich and poor in chlorophyll. Kelly and Conrad (1969) used color aerial photography above clear, tropical water conditions in their study of shallow water benthos. In 1971, Kelly presented results showing the method could also be used in turbid, temperate waters to a depth of four meters. The work of R. E. Stevenson and Nelson (1968) resulted in an index of ocean features photographed from Gemini spacecraft. From spacecraft-generated photographs of the Gulf of Mexico, Lindner and Bailey (1969) correlated shrimp catch records with turbid water distribution. Mairs (1970) provided coastal oceanographic and sedimentologic interpretation of selected Apollo IX space photographs (Figure 4).

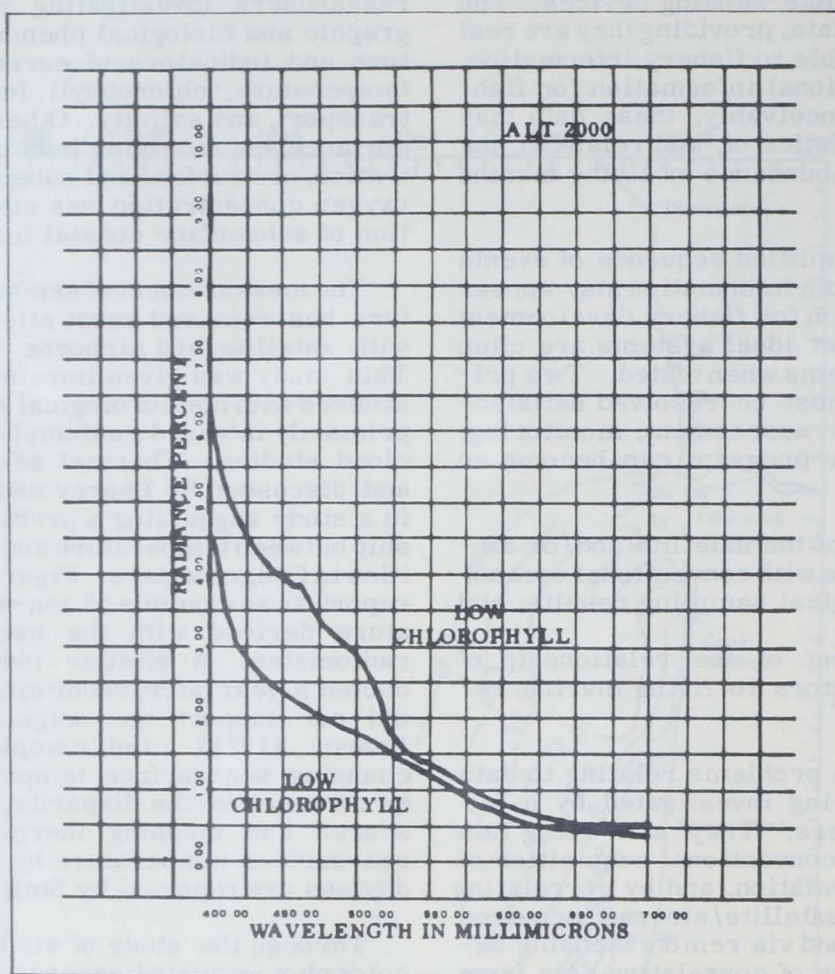


Fig. 3 - Spectra of Sunlight Backscattered from Chlorophyll-Rich and Chlorophyll-Poor Areas at 2000 Feet.

The measurement of sea-surface salinity by aircraft-mounted remote-sensing systems is in a theoretical stage. However, some experimentation has been done. Droppleman and Mannella (1970) used a passive microwave radiometric sensor system in their study of salinity variations of the Mississippi River plume.

The Earth Resources Laboratory (ERL), near New Orleans at the Mississippi Test Facility (MTF), is investigating sea-surface salinity measurements using remote-sensing techniques. Other remote-sensing systems and research applicable to fisheries has been done and is continuing by Roithmayr (1971) in his work with fish-school identification using low-light-level imagery. Investigations in fish-spectral signatures and the possible identification of fish-generated surface oil slicks may provide more fishery tools.

Potential applications of remote sensing to fisheries have been described by W. H. Stevenson and Johnson (1970), Drennan (1971, Figure 5), R. E. Stevenson (1970), Maughan (1969), and others.

#### FISHERIES

Expansion of world capability to harvest the known fish stocks has demonstrated man's capability to overexploit them. Some stocks, herring and menhaden in the Northwest Atlantic Ocean, for example, have been fished far below their capacity to produce large, sustained, harvestable surpluses. Current harvesting and management practices are based upon a very rudimentary knowledge of the marine ecosystem. To compound these problems, the use of the oceans as a dumping area for man's wastes can pollute the marine environment, and ultimately reduce its capacity

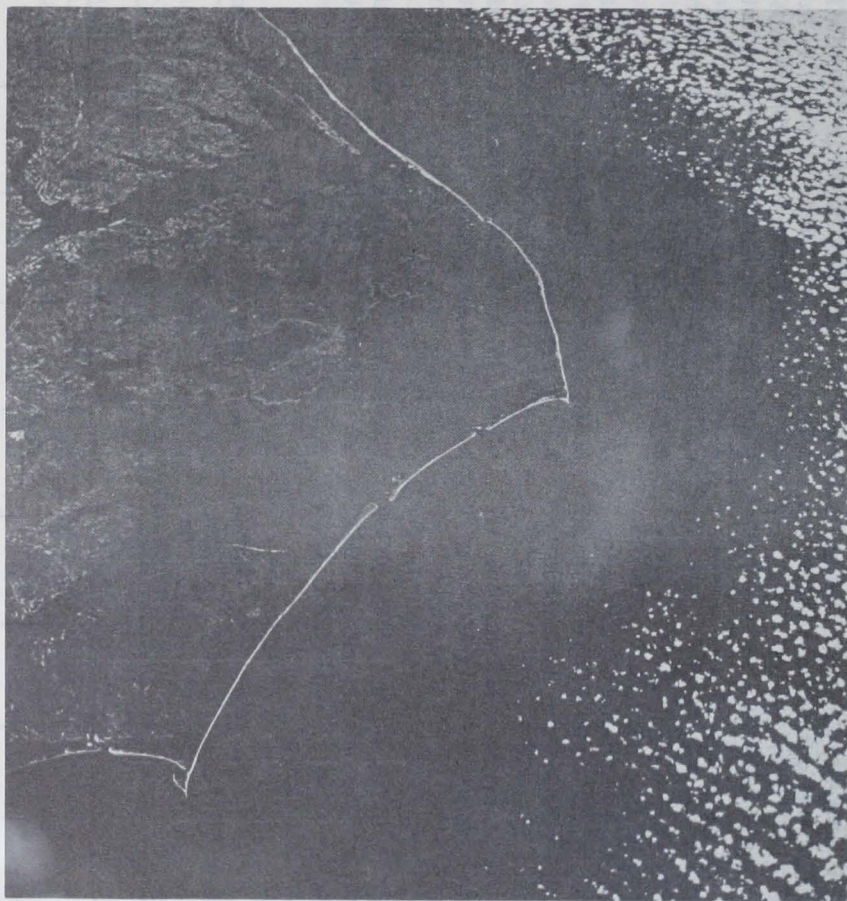
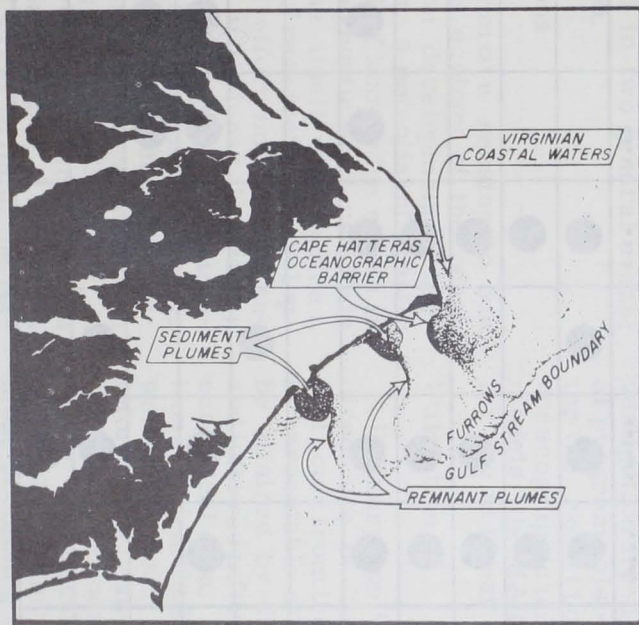


Fig. 4 - Oceanographic Interpretation of Apollo IX Photograph AS9-3128.

to sustain these resources. This is particularly dangerous for coastal waters, where increasing pollution and other environmental modifications occur, and where many important fish and shellfish resources are found.

The marine ecosystem is an extremely complex system. It consists of many organisms of diverse life forms interacting with one another and with the physical environment. The dynamic nature of this system is known mostly through conceptual models. This is due to the facts that significant biological events in the ocean take place over a large scale in time and space--and the difficulty and expense of making observations in the sea. The models are not adequate to account for the large natural fluctuations that occur frequently in animal populations. Perhaps this should not be surprising because the models are based on a patchwork of studies, generally unrelated in time and space, and usually very limited in scope.

In particular, there has been a tendency to divorce physical and biological oceanographic studies.

Physical oceanographers have stressed investigations designed to determine the processes controlling the large-scale patterns of oceanic circulation; by comparison, they have used relatively little effort in many areas of high biological productivity, particularly the coastal regions. There, physical processes are very complex and significant changes in currents, temperature, etc., occur rapidly.

For their part, biologists have concentrated their studies over continental shelves and regions of upwelling, where nutrient levels and production of living resources are high; generally, they have worked without the benefit of adequate concurrent studies of the physical environment to help determine the interactions between the biotic and nonbiological factors. New approaches are required where both biological and physical environmental studies are pursued concurrently.

Integration of oceanographic and fishery resource information is now being attempted by several national agencies. The Natural









OBSERVABLES	SENSOR							
	 MULTI-SPECTRAL CAMERA	 METRIC CAMERA	 LASER	 SPECTRO PHOTOMETER	 RADIATION THERMOMETER	 THERMAL MAPPER	 LOW LIGHT LEVEL TV	 MICRO WAVE RADIO METER
SCHOOLS	●	●	●	●			●	
FISH COLOR	●			●				
WATER COLOR	●	●		●				
SURFACE ANOMALIES	●	●		●			●	●
UPWELLING	●	●		●	●	●		●
BIOLUMINESCENCE							●	
PLANKTON			●				●	
CURRENTS	●	●		●	●	●		●
SURFACE TEMPERATURE					●	●		●
SEA STATE		●	●					●
FISHING ACTIVITY	●	●		●			●	

Fig. 5 - Remote Sensors and their Potential Application to Fisheries.



Environment Research Council (NERC) of the United Kingdom, for example, is developing a comprehensive program to study the biological/environmental relationships in the North Atlantic and North Sea. In the United States, a similar national program called Marine Resources Monitoring, Assessment, and Prediction (MARMAP) is under development. MARMAP will monitor fluctuations in the distribution and abundance of various fishery resources and relate them to environmental factors and to exploitation by man. Also, it will provide the mechanism to establish a comprehensive description of other marine ecosystems in terms of the distribution, composition, and interrelationship of biological communities.

Oceanographic information obtained from remote-sensing data can play a critical role in these programs. One example is the identification of thermal fronts obtained from the NOAA/ITOS satellite system (Figure 6). Photographs, available for direct readout, identify the thermal boundaries in photographic form and can be digitized by computer. However, the usefulness of this information in fisheries other than to deploy ships is not well defined. The NERC and MARMAP programs previously mentioned include surface experiments to improve the relationship of oceanographic data to fishery resources.

The application of remote sensing to fisheries can be classed in two general areas: ecology and utilization.

#### Ecological Applications

Application of remote sensing to our understanding of the ecology of the ocean depends primarily on development of bio-environmental models. A potential of greatly accelerating our level of knowledge exists in the ability to conduct synoptic surveys. This new survey technique itself will require a considerable amount of research and development--and concerted effort not to bend the results to fit classical procedures, but rather to use the two elements to advance the state-of-the-art. Concurrently, incomplete models of oceanic processes must be altered or completely restructured using the new knowledge from remote-sensing data. Examples of present work to develop these modifications are in the National Environmental Research Council programs of Great Britain, the National Oceanic and Atmospheric Administration programs in oceanography, the National

Aeronautics and Space Administration's Earth Resources programs in the United States, and others.

In the fishery world, resource status models relating fish stocks to environments are just coming into their own. Models are being developed to relate major environmental indicators to the quantification and qualification of fishery stocks. These types of models are being developed by NOAA's National Marine Fisheries Service. The models, initially based on classical data, are designed to advance our understanding of the ecological relationship. For example, remotely sensed thermal data from ITOS satellites are being correlated with yellowfin tuna models developed by the Inter-American Tropical Tuna Commission. The purpose is to determine the practicability of using satellite-obtained sea-surface data as a major component in predictive resource availability models.

Validation of any model will require the acquisition of a considerable amount of ground-truth data currently available through classical survey techniques. By intensifying oceanographic and fishery survey activities for the next 5 years, we can expect to identify the factors necessary to establish the validity of remote-sensing data applications to the fisheries. The surveys planned in international efforts such as CICAR, UNDP special fund projects, and the FAO Indian Ocean Investigation are significant examples. National programs also will contribute to establishing the relationship of remote-sensing oceanographic information to resource status models: the MARMAP program, and a similar one in Great Britain, for example.

#### Utilization

Primary application of remote sensing to direct use of fishery resources most likely will come from the location and identification of harvestable stocks. Such information will be attained by direct sensing from aircraft and inferred information from oceanographic ecological data. Application of direct location and identification of fishery stocks is not well understood. Techniques for correlating information from ocean surface with patterns taking place beneath it are not now available. These techniques are projected to become available within the next 3 to 5 years. The most promising techniques being developed in the U.S. are low-light-level image intensification and laser instrumentation systems.

1-T08 1 Orbital Data

16.3 - 12.3 m

11 grey scale steps 1/2° K

NOAA-NLEB-EPG

October 15, 1979  
0000 GMT

Black - Cold

White - Warm

Location of thermal fronts from Satellite Data. NOAA/TTOB Infrared image of east coast of US showing large thermal characteristics in coastal waters as well as distant Gulf stream boundaries.

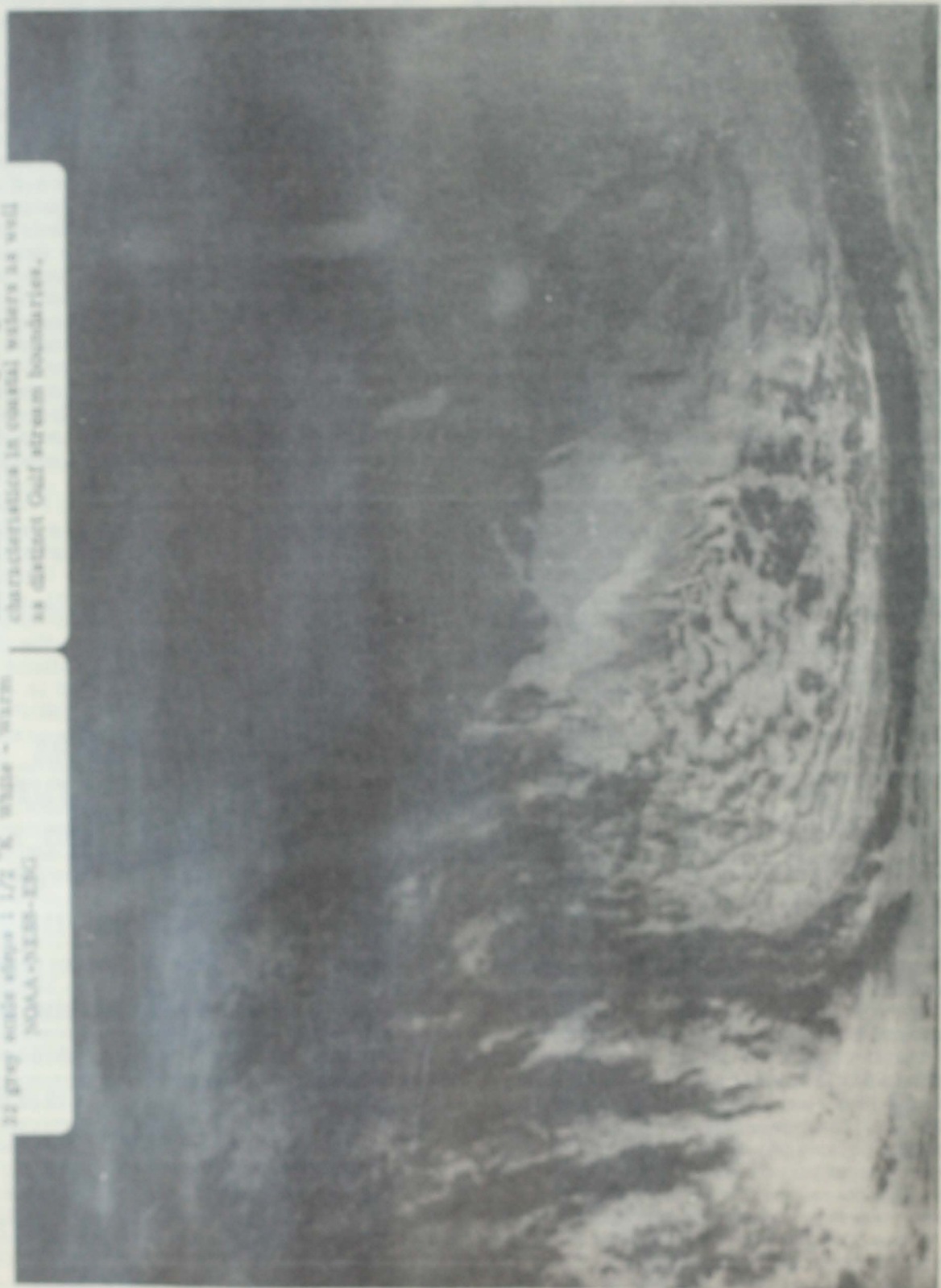


Fig. 4 - Location of Thermal Fronts from Satellite Data. NOAA/TTOB Infrared Image of U. S. East Coast Showing Thermal Characteristics in Coastal Waters and Distant Gulf Stream Boundaries.

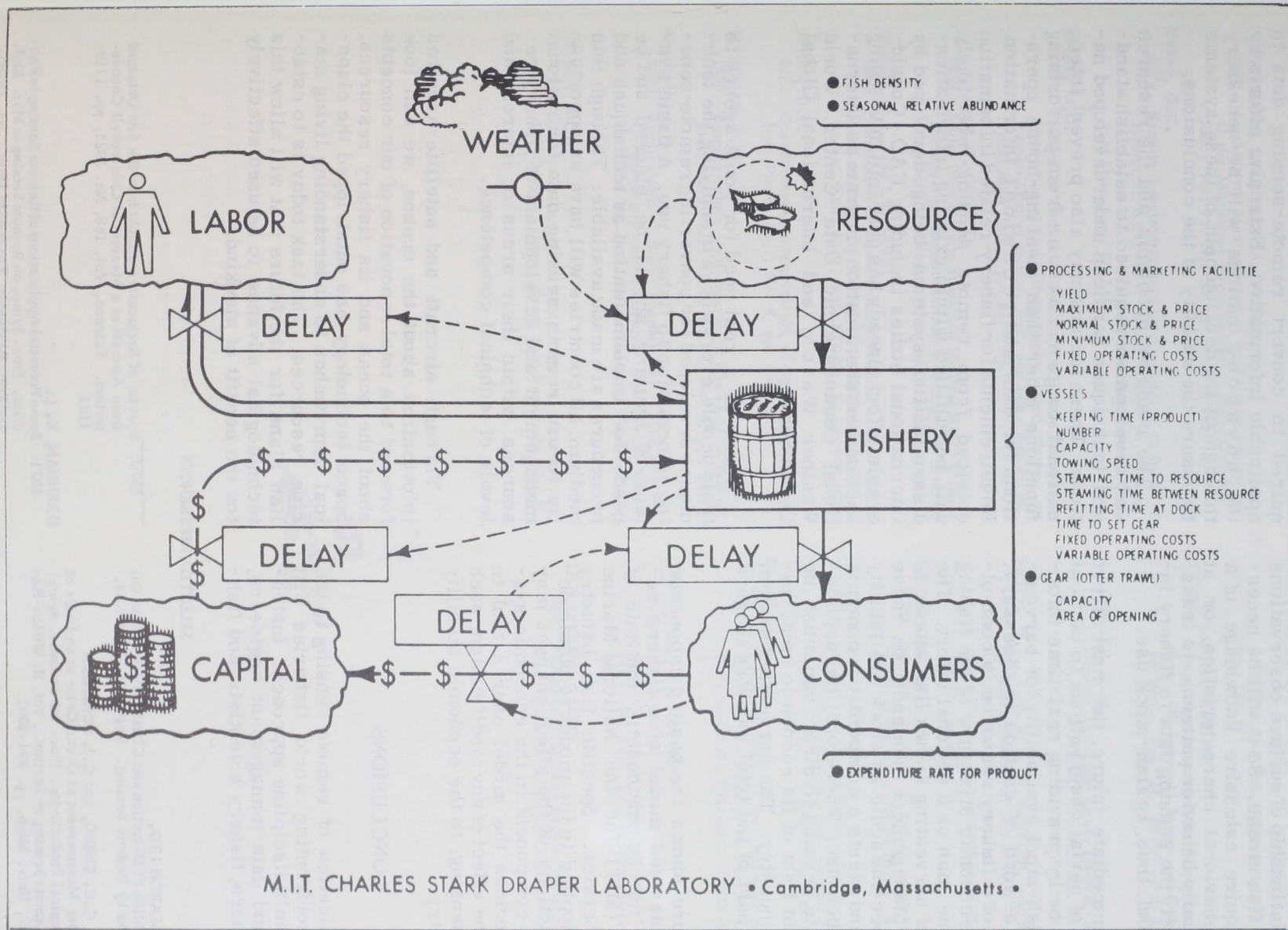


Fig. 7 - Basic Components of a Computerized Model of Any Given Fisheries--Developed by Massachusetts Institute of Technology for NMFS.

To use these, it will be necessary to understand the relationship of surface observations to existing fish stocks. So it will be necessary to acquire extensive knowledge of a species' behavioral characteristics, or at least the family behavior patterns, to transfer effectively the sensing data to fishery information and, thus, to fish-stock use.

In the immediate future, the most direct application of aerial observations to tactical fishing may be by providing real-time information on fish-stock availability for harvesting. Here a word of caution is necessary. Utilization of a fishery resource is controlled by the economic structure of the fishing industry, one man or a national effort. The capability of harvesting known fish stocks is available. Management demands on these resources become acute as stock availability decreases and exerts a competitive economic demand on their use. Therefore, the application of remote sensing to direct use must be considered in light of its economic contribution to the industry. The harvesting system is only one part of the total industry (Figure 7).

This figure shows the basic components of a computerized model of a fishery developed by the Massachusetts Institute of Technology (MIT) for the National Marine Fisheries Service. Specific fish industry inputs are applied to the model to obtain detailed predictions of the effect changes may make on any component in the economic system. It provides the model user a tool to determine the effect of any modification, such as remote sensing, to the economic stability of the industry.

## CONCLUSIONS

The application of remote sensing to the problems confronting world fisheries will require a multidiscipline approach. Instrumentation and data-management engineers, oceanographers, fishery scientists, and fish-

ery experts working as a team will be required to convert remote-sensing data to applicable information. Extensive efforts by the advanced nations will be necessary throughout the development of these systems to ensure the validity of the conclusions.

The complex problems and the research and development required to establish standard techniques handicap underdeveloped nations. These factors may also prevent international organizations from performing functions other than clearing-house operations for data and technical information. Requirements for fishery-related information obtained from remote sensing most likely will be fulfilled within existing information-dissemination systems being developed by international bodies including FAO. Considerable effort already has gone into developing such data-dissemination program as International Oceanographic Data Center, World Weather Watch, and International Global Ocean Survey.

There is a real need for some agency to train people everywhere in applying the techniques developed for converting remote-sensing information to fishery use. A basic system of training should be planned and be ready for implementation as techniques and procedures are made available. Through this medium, all countries will have an opportunity to use remote-sensing data for rational management and development of fishery resources within their areas of interest and levels of technical competence.

Through aircraft and satellite-acquired information about the oceans, we can look forward to a total renovation of our concepts about the ocean and its fishery resources. Space technology has outstripped the classical approaches to understanding living marine resources. The task today is to establish plans for the future that will allow this technological advance to be used effectively for the benefit of mankind.

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