Overview of Satellite Remote Sensing Applications in Fisheries Research

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Background

Satellite remote sensing can be an extraordinarily effective and powerful tool in fisheries oceanography research, fisheries management, marine protected species research and management, and operational fisheries oceanography. The promise of satellite remote sensing technology for fisheries research, management, and exploitation has been recognized since the 1960's when the first visible and infrared images of the earth's surface were obtained from orbit. Limited uses of early satellite data were made in fisheries demonstration projects conducted in the early and mid-1970's (Kemmerer et al. 1974; Savastano et al. 1974). A number of important fisheries applications were achieved in the 1980's (Lasker et al. 1981; Fiedler 1983 and 1984; Fiedler and Bernard 1987; Fiedler et al. 1985; Laurs et al. 1984; Maul et al. 1984; and others). Significant strides, progress, and expansion in the utilization of satellite remote sensing data for meeting the needs of fisheries researchers for marine environmental information have been made during the recent decade. This has occurred primarily because of increases in the availability and improvements in the access to some satellite data, the development of easy to use satellite data processing and display software packages combined with low cost computer hardware systems, and the increasing awareness of the successes in demonstrating the application of the technology to marine fisheries problems.

Noteworthy advances have also been made in the use of satellite-derived ocean measurements to meet the operational fishery oceanography needs of various segments of fisheries industries. In the US, these have progressed from the first use of satellite-received data in fisheries-aids charts provided to cooperating tuna fishermen in the eastern tropical Pacific (Laurs 1971), to satellite-derived ocean boundary charts provided to salmon and albacore fishermen on the West coast (Short 1979; Breaker 1981) and lobster and other coastal fishermen along the East coast (Chamberlain 1981; Cornillon et al. 1986), to demonstration experiments of satellite-derived ocean products for commercial fishing operations (Hubert 1981; Montgomery et al. 1986). Several papers describing operational fishery advisory products based on satellite-derived data, which are available for use in commercial fisheries are found in Le Gall (1989).

Capitalizing on the experience gained from the Government sponsored fishery-advisory programs using oceanic satellite measurements, several US private companies presently market value-added, near real-time Advanced Very High Resolution Radiometer (AVHRR) satellite imagery and digital data products tailored to the specific needs of various segments of the US commercial and sportsfishing industries (Anon. 1994; Wynn 1989). The private sector is also planning to market fishery advisory services based on ocean color measurements made by the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) sensor that has been built and will be launched and operated by a commercial venture (Lyon and Willard 1993).

Nevertheless, in spite of the impressive gains and advances, the full potential of satellite remote sensing for fisheries applications, and particularly for applications to protected species issues, still remains untapped and underdeveloped. This is especially the case in the US, which is ironic because this country has constructed, launched, and operates the majority of the satellite systems that provide data presently used in fisheries applications throughout the world. Several other countries have built on the early efforts and learning experiences gained in the US in satellite applications to fisheries and now appear to have surpassed the initial lead of the US. This is certainly true for Japan (Shinomiya and Tameishi 1988; Yamanaka et al. 1988), some of the European countries, and perhaps, even China (Bilan and Xuejia 1990; Huang 1994).

Literature Reviewing Fisheries Applications of Satellite Remote Sensing

A recent review of the applications of oceanic satellite remote sensing to fisheries is given by Fiuza (1990). Another relatively current survey is found in

Johannessen et al. (1989). Laurs and Brucks (1985) review fisheries applications in the US. Examples of uses of satellite imagery in eastern North Pacific fisheries are given in Fiedler et al. (1985). Yamanaka et al. (1988) describe the utilization of satellite imagery in Japanese fisheries and Hirano and Mizuno (1992) provide an overview of current and planned expansions in Japanese operational fisheries oceanography that will result from expanded use of data from satellite systems. Gower (1982) gives a summary of the different kinds of remote sensing data relevant to fisheries science and oceanography and Montgomery (1981) discusses the utility of satellite imagery to ocean industries, including fisheries. Two publications issued by the UN Food and Agriculture Organization (FAO) deal with the application of remote sensing technology to marine fisheries (Butler et al. 1988; Le Gall 1989).

Why Satellite Remote Sensing Data Can Be Important in Solving Fisheries Problems

Variations in marine environmental conditions affect the distribution, abundance and availability of marine fish populations. Likewise, variations in ocean conditions influence the vulnerability and catchability of fish stocks. In order (a) to understand, model and predict the effects of ocean conditions on marine fish populations, (b) to efficiently harvest marine fish stocks, and (c) ultimately, to effectively and rationally manage many marine fisheries, information is required on the "*changing ocean*," rather than the "average ocean".

Satellite remote sensing is exceptionally well-suited for measuring and monitoring the "*changing ocean.*" It offers the combined benefits of large-scale synopticity, high spatial resolution, and frequent repeatability of coverage. The primary disadvantages are that satellite measurements are mostly limited to the very near-surface film of the ocean and visual and infrared measurements are restricted to cloud-free areas. However, these drawbacks are not always serious. In many oceanic regions, conditions at the surface have been found to be representative of those in the upper 100 - 250 m (Godfrey and Ridgeway 1985 and others). The cloudiness problem can often be at least partially overcome by combining infrared or visual images of the same area acquired over several days, resulting in a temporally averaged image which oftentimes contains extensive cloud-free areas. The use of new neural network methods for satellite image processing has great potential for reducing the impacts of cloudiness (Yhann and Simpson 1995).

Satellite Oceanic Remote Sensing Cannot Replace *In situ* Measurements

It must be emphasized that oceanic satellite remote sensing systems are not, and cannot be, replacements for ships, data buoys, fixed and floating instrument arrays, and other means of making *in situ* measurements of the ocean. As noted earlier, oceanic measurements made by satellite systems, except for ocean color which is integrated over depth depending on water optical characteristics, are restricted to the most exterior portion of the ocean. The conventional means of making oceanographic observations are crucial for obtaining information on the status of the interior of the ocean and for calibrating and validating measurements made from space.

Types of Satellite Data Used in Fisheries Applications

Most fisheries and protected species applications of satellite remote sensing have made use of AVHRR infrared temperature and Coastal Zone Color Scanner (CZCS) ocean color measurements. This has been the case primarily because these data (a) have been readily available, (b) after conversion to SST and chlorophyll or related optical data, the derived data measurements can be used directly in marine resource applications, and (c) there is general understanding and confidence in the meaning of the satellite-derived data. The marine science community, and especially fisheries oceanographers, are eagerly awaiting the launch of ocean color sensors to replace the CZCS, which failed in 1986.

There has been only very limited use in fisheries applications of satellite data from active sensors. However, it is highly likely that as Synthetic Aperture Radar (SAR) satellite data become more available, its use will markedly increase. SAR can be used as an all-weather sensor to define ocean features, e.g., eddies, frontal structure, river plumes, etc., that form important habitats for marine resources. SAR data also has tremendous potential for detecting and monitoring fishing activities, possibilities for detecting schools of large pelagic fishes and marine mammals (see later section), and opportunities for supporting fishery management actions. Only a few fisheries studies dealing with transport of developmental stages (see description in Laurs and Brucks 1985), have taken advantage of oceanic wind structure measured from space by scatterometers. Nevertheless, information from scatterometers have high possibilities for expanded fisheries applications. Mitchum and Polovina (pers. comm.) are evaluating the use of altimeter data to define the occurrence and locations of high levels of mesoscale circulation activity believed to be important in central North Pacific fisheries. Some coastal and coral reef fisheries studies have employed the use of LANDSAT (Kemmerer 1980) or SPOT (Bour et al. 1986; Preston 1991) data to define habitats important to inshore and reef fisheries.

The ARGOS satellite location system is widely used in fisheries, marine mammal, and sea turtle research investigations. Global Positioning System (GPS) location systems are also used in fishing vessel monitoring systems and are under development for use on marine mammals. The eventual development of the operational system using low earth orbit satellites (Seay 1994) will provide fisheries and protected species researchers and managers with a huge expansion in the possibilities of satellite networks for both data communications and position determination. Cooperative efforts are underway between the NMFS Honolulu Laboratory and Commonwealth Scientific and Industrial Research Organization (CSIRO) Division of Fisheries in Hobart, Tasmania to use communications satellite technology for transmitting data collected on electronic "archival tags" that will be programmed to disengage from a fish and "pop-up" to the surface for relaying data via the ARGOS satellite system.

Sources of Satellite Data

For US fisheries researchers, the major source of real-time and near real-time AVHRR satellite data is the NOAA CoastWatch Program. There is little doubt that the expansion during recent years in fisheries applications using AVHRR High Resolution Picture Transmission (HRPT) satellite data is the direct result of the CoastWatch Program. This successful NOAA program, which had its beginnings to fill a need for satellite data for use in research regarding marine mammal deaths and fisheries needs on the east coast, has seven sites throughout the mainland US, Alaska, and Hawaii. Five of these sites are co-located at NMFS laboratories. The primary mandate of the CoastWatch program is to make satellite data readily available to federal, state and local agency managers and investigators, and to university scientists for use in marine research, policy and management decisions. Actions are underway to attempt to make satellite data from new sensors available at some CoastWatch sites. The new satellite data include ocean color from the planned US commercially owned and operated SeaWiFS sensor on the SeaStar satellite and the Ocean Color and Temperature Sensor (OCTS) on the Japanese Advanced Earth Observing Satellite (ADEOS), SAR data from several satellite systems, and possibly satellite wind scatterometer data. Other sources of satellite data for fisheries applications have been NASA, NOAA/NESDIS, and university satellite receiving stations. For further information on available sensors, see papers in this volume by Pichel, Maynard, and Holt and Digby.

Examples of Satellite Remote Sensing Applications in Fisheries Research and Management and Protected Species Research

No attempt will be made here to provide a comprehensive review of fisheries research and management applications of satellite remote sensing. Instead, categories of research and management applications utilizing satellite-based technology, with examples of representative studies will be given. The categories are: fish early life history and survival, definition of marine fish habitat and migration patterns, stock assessment, fishery management, protected species, and operational fishery oceanography in support of research cruises.

Fish Early Life History and Survival. Satellite ocean measurements are becoming increasing more common in research concerning the early life history and survival of marine fishes. The spawning habitat for northern anchovy in the southern California Bight can be defined using a combination of satellite-derived sea surface temperature (SST) (Lasker et al. 1981) and surface chlorophyll distributions (Fiedler 1984). In the Gulf of Mexico, larval fish assemblages have been related to the Loop Current boundary determined by satellite images (Richards et al. 1993). AVHRR satellite imagery played an important role in the investigation of the distribution and advective transport of larval fishes over the continental shelf off North Carolina (Govoni et al. 1994).

Marine Fish Habitat and Migration Patterns. A relatively large number of studies of marine fish habitat and research on pelagic fish migration have utilized satellite remote sensing data. For example, Laurs et al. (1984), using AVHRR and CZCS data demonstrated the role of oceanic frontal structure in the habitat and migration patterns of albacore. Reddy et al. (1995) used satellite-derived sea surface temperatures to show that distribution and movement patterns of southern bluefin tuna and albacore off Tasmania, Australia are related to persistent mesoscale, warm-core eddies and strong thermal fronts. Similar findings were reported for southern bluefin tuna off western Australia by Myers and Hick (1990). Using AVHRR satellite data, Kumari et al. (1993) found that the distribution of yellowfin tuna in waters off the coast of India are related to thermal boundaries. Stretta (1991) used a variety of satellite data as input into a proposed model for tuna fishing in the Gulf of Guinea region. Using satellite imagery and advanced image analysis techniques, Podesta et al. (1993) found that the probability of very high catch rates in the US longline fishery for swordfish in the Atlantic was greater in the vicinity of SST fronts. Satellite infrared observations of Kuroshio warm-core rings and their influence on Pacific saury migration was reported on by Saitoh et al. (1986). Satellite-derived ocean temperature and chlorophyll were used by Herron et al. (1989) to define the habitat of butterfish in the northeastern Gulf of Mexico.

Stock Assessment. Cram et al. (1979) used satellite ocean color data to minimize the search component of fishing effort and to refine stock assessments of pilchard stocks off South Africa. Ocean temperatures and habitat information determined by satellite remote sensing are being used in research to support stock assessment of large oceanic pelagic fishes and other living resources in the Western North Atlantic Ocean (Browder and Turner 1992). Satellite-derived environmental data are being incorporated into general linear models to develop standardized annual abundance estimates for improved stock assessments.

Fisheries Management. The application of satellite data to near real-time bluefin tuna catch projections for quota management is described by Browder et al. (1992). Also see Petit et al. (1992) and Clemente-Colon (1995) in the following section concerning the potential for direct detection of fish schools by satellite.

Protected Species. AVHRR satellite imagery is being used to reduce the impact of commercial trawl fishing on populations of threatened and endangered sea turtles (Chester et al. 1994) and to identify sea turtle habitat (Epperly et al. 1995) off the east coast of the US. Satellite remote sensing and GIS technology are being used in ecological investigations of sea turtles and marine mammals in the Western North Atlantic (Huang et al. (1992).

Operational Fishery Oceanography in Support of Research Cruises. The use of AVHRR satellite data for guiding fisheries research vessel operations is important and relatively widespread in the US. For example, most federal and many state or university fisheries oceanography cruises conducted in the Pacific and Gulf of Mexico have some sort of real-time or near real-time satellite data support. The same is generally true in the Atlantic, however, apparently it is not as routine. In some cases, the satellite-derived data simply consists of isotherm charts transmitted by radio or telephone facsimile. It is more common, however, to transmit digital satellite data or products from shoreside satellite image processing sites to research vessels at sea. In some cases, research vessels are equipped with systems for direct reception of HRPT or Automatic Picture Transmission (APT) AVHRR satellite data. An important use of satellite data is to locate ocean features important to the success of the mission of research vessel operations and to guide sampling accordingly. The satellite data are also used to interpolate and to extrapolate *in situ* oceanographic measurements made from research vessels.

Potential For Direct Detection of Fish Schools, Fishing Activities, and Marine Mammals Using Satellite Remote Sensing

Direct detection of fish schools, fishing activities and marine mammals has not been possible using satellite measurements that have generally been available to the civilian community. However, recent studies conducted off the western Mediterranean coast demonstrate that tuna schools, marine mammals and fishing activities can generate a SAR signal modulation and indicate that it is likely that with further research, it will be possible to convert radar images to pelagic fish school abundance or fishing effort estimates (Petit et al. 1992). Research conducted off Canada (Freeburg et al. 1995) has verified the application of space-based radar systems for fisheries monitoring, control and surveillance. SAR imagery has been used effectively in fishery surveillance in an Alaskan herring fishery to monitor fishing activity and could be used to manage the fishery (Clemente-Colon et al. 1995). It also appears that SAR imagery can be used for surveillance of illegal fishing activities on the high seas, e.g., detecting illegal pelagic drift gillnet fishing (Montgomery, D.R., pers. comm.). Direct observation of fish schools, marine mammals, and sea turtles may be possible from classified satellite assets.

Actions That Can Assist the US to Take Advantage of the Full Potential That Oceanic Satellite Remote Sensing Offers For Fisheries Applications

Several actions will be required in order for the US to take full advantage of the potential that satellite remote sensing can contribute to solving problems and issues in marine fisheries and protected species research and management. These actions include:

- (1) senior officials of Federal and State marine fisheries agencies need to be educated to understand the usefulness of satellite remote sensing as a major tool for use in solving appropriate fisheries and protected species research and resource management issues;
- (2) commitments are needed between the NOAA Assistant Administrator's for NMFS and NESDIS, with follow-through by appropriate senior staff, to enhance and where possible to fully develop US capabilities in satellite applications to marine fisheries and protected species;
- (3) adequate funding is required to conduct research on the application of satellite remote sensing to appropriate fisheries and protected species issues;
- (4) resources are needed for training fishery research scientists in applying satellite remote sensing to agency fisheries and protected species research needs;
- (5) NOAA should establish university fellowship programs in satellite remote sensing applications to fisheries and oceanography (similar to programs sponsored by the NWS for meteorological applications) to train students that show promise as prospective fishery scientists;
- (6) a satisfactory data management system is required which is linked with GIS for investigations using multidisciplinary data, including oceanic satellite-derived measurements; examples of systems that may be appropriate are described by Savastano and Bane (1986) and proposed by Simpson (1992); and
- (7) provisions must be made to ensure easy access by fishery scientists to data from new satellite sensors, e.g., SAR, wind SASS, ocean color, altimeter, etc. (this need may partially be met by efforts which are presently underway to expand the satellite data available from the NOAA CoastWatch Program).

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CHANGING OCEANS AND CHANGING FISHERIES: ENVIRONMENTAL DATA FOR FISHERIES RESEARCH AND MANAGEMENT A WORKSHOP

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