# Remote Sensing as an Aid to Fishery Management and Contingency Planning in the Caribbean

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ABSTRACT

La perceptión remota como herramienta en el manejo de recursos (naturales) se asocia cada vez más con datos provenientes de satélites. El uso de muchos de los detectores actualmente en órbita, tiene aplicación sólo en las esferas de la investigación, y los equipos y programas de computadora relacionados con la interpretación de los datos producidos por los detectores de probada aplicación práctica son generalmente costosos y requieren un alto grado de destreza técnica para su interpretación.

Este trabajo examina primeramente la percepción, se nota en la forma tradicional que utiliza la topografía del área y sus variantes. Se describen técnicas que han sido probadas en el campo y que son efectivas desde el punto de vista de costos, aplicadas a estudios del sublitoral; evaluación de biomasa de yerbas marinas; estimados de esfuerzo pesquero; vigilancia de pesquerías; erosión costera; seguimiento par metros de contaminación, evaluación de sitios para acuacultura, etc., aspectos, todos de la administración del recurso marino. Se discuten, además, las posibilidades de integrar este tipo de información con los datos derivados de los detectores a bordo de satélites y su subsiguiente an lisis y divulgación dentro de un sistema computarizado de información aplicado a un área geográfica.

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L'aménagement des ressources par télédétection est associé de plus en plus avec les données obtenues des satellites. Cependant, plusieurs des capteurs présentement en espace demeurent dans le domaine de la recherche.

L'interprétation des données obtenues de ces capteurs, même pour des applications connues, nécessite des dépenses coûteuses pour le matériel et pour le logiciel, ainsi qu'une compétence technique considérable.

Ce document adressera principalement les méthodes plus traditionnelles de la télédétection, soit la photographie aérienne et ses divers aspects. Des applications pour l'acquisition de données qui sont rentables et qui ont été prouvées efficaces seront décrites dans le contexte de divers aspects de l'aménagement des ressources halieutiques tels que: les études de la zone sublittorale; l'évaluation de la biomasse des algues marines; l'évaluation des efforts de péches; la surveillance des pécheries; la surveillance de l'érosion côtiére; le contrôle des sources de pollution; l'évaluation des sites d'aquaculture, etc. Ce document adressera aussi la possibilité d'intégrer ce genre d'information avec les données obtenues des satellites, suivit de l'analyse et la représentation de ces données `a partir d'un systéme d'information géographique `a base de micro-ordinateur.

## INTRODUCTION

Remote sensing may be defined as the acquisition of information about an object or scene without being in physical contact. It is often restricted to methods that employ electromagnetic energy (light, heat, and radiowaves) to detect and measure target characteristics. A fisherman's ability to detect the presence of fish or other environmental information without the aid of additional remote sensing devices is relatively limited. The human eye can be regarded as a remote sensor but it is sensitive only to a narrow region of electromagnetic radiation, known as the visible spectrum (0.4 - 0.7 micrometers). The human can detect sound only within the range of 16,000 — 20,000 cycles/second and the human sense of smell is not responsive to odors in concentrations of less than 1 ppm. Remote sensing can overcome most of these limitations.

Historically, fish were located by fishing on a trial and error basis. Today, such traditional search methods have been replaced by the direct detection of fish with echo sounders or sonar (*e.g.*, the cod and herring fisheries), or by the use of aircraft for fish finding (*e.g.*, the tuna and menhaden fisheries). Thus, it has been possible to reduce the time expended searching for fish and also the time wasted on the unnecessary setting and hauling of gear. The use of radar in fishing vessels further increased efficiency (and safety) by providing a reliable navigation aid. In 1957 the world's first artificial satellite "SPUTNIK" was launched by the USSR. It provided a new platform for the installation of remote sensors. Since that historic event, the number, size, and complexity of satellites and their sensors have increased tremendously. Today, a large array of sensors can be utilized to directly or indirectly observe oceanographic parameters, many of relevance to fisheries, *e.g.*, temperature, currents, wave height, wind speed and direction, ocean color, chlorophyll content, bathymetry, etc. Oceanography profited immensely from this new era of remote sensing, and in particular, from the large geographic coverage possible from satellites, the repeatability of data acquisition, and the ability to obtain data under all weather conditions with some sensors. The use of real time satellite data for directing fishing operations, however, is still limited to a few industrialized fishing nations (Colwell, 1983; Mouchot *et al.*, 1987).

## APPLICATION OF REMOTE SENSING TO FISHERIES: AN OVERVIEW

The sea covers two thirds of the earth's surface and, to a large extent, man is still dependent on it for food which includes fish, shellfish, marine mammals, turtles, aquatic plants, and algae. In the past, remote sensing was used to detect a living resource and therefore assist in its exploitation. Today, it is being used for resource estimation and conservation in addition to exploitation (Colwell, 1983; Cracknell, 1983; Mouchot *et al.*, 1987).

Remote sensing techniques can be utilized in three ways to detect fishery resources and to assess their potential:

1. Direct methods of fish detection.
2. Indirect methods of fish detection.
3. General aids to fishing operations.

**Direct Methods of Fish Detection**

The most primitive and still widely used method of remote sensing in fisheries is visual fish spotting. Major fisheries such as tuna and menhaden are dependent on visual fish spotting by aircraft to direct their fleet.

Aerial photography per se is of little direct importance to fishermen as it does not provide information fast enough to permit them to locate mobile fish schools. Aerial photography, however, can be of great assistance to fishery scientists and managers as it provides information about the distribution and relative abundance of many marine fish, their habitat availability, and about a host of parameters which may influence marine resource distribution and abundance.

Echo sounders and sonar have been in use as remote sensors at least for the last 50 years and now are used widely by the fishing fleets of the world. Sonar is useful not only for the detection of fish but also as a technique for biomass estimations.

**Indirect Methods of Fish Detection**

Estimation of fishery resources can be assisted by the measurement of parameters affecting the distribution and abundance of that resource. Most of the research dealing with environmental effects are concerned with the correlation of a single parameter with the spatial and temporal distribution of fish. It is probable, however, that fish generally respond to the total sum of the environmental factors. Thus, it becomes necessary to correlate a large number of parameters, obtained by remote sensing techniques, with the distribution of fish.

The environmental parameters most commonly measured from airborne and spaceborne sensors are as follows:

1. Temperature.
2. Chlorophyll.
4. Water clarity.
5. Sea state.

Satellites have the advantage of observing a large area of the earth's surface synoptically and repetitively. The importance of a synoptic view is that data can be obtained from many points over a large area at the same time. With conventional airborne methods it would require considerably more time to cover the same area, however resolution would be markedly increased.

**General Aids to Fishing Operations**

Satellites can assist the fishing industry in many ways other than finding fish. Most of these aids are common to shipping in general. Types of assistance that satellites can offer include:

1. Search and rescue operations: These can be carried out with the help of environmental satellites such as Seasat-1 (now defunct) and geostationary communication satellites. The former was used to detect vessels and the later to form a communication link between a ship in distress and a land stations (the SARSAT-COSPAS satellites).
2. Charts and weather reports: Environmental satellites such as NOAA, SEASAT, LANDSAT and HCMM can provide weather information over a wide area at a given time. This may assist fishermen in planning their fishing operations. Many hazards such as reefs, islands and shoals have been shown to be located incorrectly on charts. Usually the information

on an uncharted hazard, when detected on a satellite image, is sent to all vessels in the area. In higher latitudes, ice and icebergs are major hazards. Radar sensors in space or in an aircraft assist in identifying ice, classifying ice maturity, and spotting icebergs.

REMOTE SENSING WITH AERIAL PHOTOGRAPHY

The applications and benefits of aerial photography taken from fixed wing aircraft or helicopters has tended to be overshadowed by the advent of satellites. The acknowledged shortcomings of some of the experimental spaceborne sensors, their scientific as opposed to commercial objectives, and the considerable expense associated with their data acquisition, analysis, and utilization has forced a reevaluation of the historic methods of airphoto acquisition and analysis and the use of aerial photography as an aid to marine resource management. The resolution of aerial photography cannot be matched by spaceborne sensors, at least in the civilian as opposed to military satellites.

The application of aerial photography in recent years in Atlantic Canada may be of value to fisheries personnel in the Caribbean area and elsewhere. Airborne platforms, cameras, and films will be discussed briefly and a number of case studies will be reviewed in which aerial photography has played a major role:

1. Airborne platforms: Virtually any single, twin or multiengined aircraft or helicopter is a suitable platform if it allows a camera(s) to be safely mounted either internally or externally. Internal mounting has the advantage of permitting changes of camera and film in flight, avoids weather damage to the equipment, and reduces aerodynamic drag. High wing monoplanes, such as the Cessna 172, have the advantage of providing good visibility for the camera operator;
2. Cameras: There are five major categories of interest. Prices of cameras vary considerably and some may be rented:
   a) Large format aerial survey camera (9 x 9 inches) *e.g.*, Wild RC-8 and RC-10, Zeiss RMK. These are priced from $30,000 to $200,000 (Canadian).
   b) Small format reconnaissance camera (70 mm) *e.g.*, Vinten, Hasselblad ($2,000 - $7,000 Canadian).
   c) Video camera ($5,000 - $10,000 Canadian).
   d) Low light level television camera-LLTV ($20,000 Canadian).
   e) 35 mm camera.
3. Films: There are numerous types of aerial photographic film available. The following is a partial list of films and some of their uses, advantages, and disadvantages:
   a) Color positive film (i.e. slide film), used for depth penetration, location of subsurface features, etc.: less expensive than color negative film (standard color film) which requires the production of paper prints; good resolution (detail); and excellent visual presentation aid.
   b) Standard color film, used for land typing, etc.: good resolution; easy to use in a stereoscope; excellent for text illustration.
   c) Color infrared film, used for shoreline classification, vegetation typing, and condition assessment, etc.: excellent for comparison with normal color films; advantage of viewing a portion of electromagnetic spectrum which complements the visible range; no water penetration

(the water is black). This can be used to advantage when locating water bodies;

d) Color video film, used for depth penetration, etc.: quick turnaround and relatively cheap; suitable for monitoring dynamic parameters; poor resolution; individual frame can be transferred to base map by zoom transferscope.

e) Black and white film, used for land typing, etc. The black and white prints made from this film are: less expensive than color prints; useful for general coastal studies; easy to reproduce; and make excellent base maps.

## CASE STUDIES

### Estimation of Intertidal Vegetation Coverage

Color infrared photographs were used to estimate vegetation distribution and abundance, often to the species level, along the intertidal zone of Passamaquoddy Bay, New Brunswick. The tidal amplitude exceeds 20 feet in this part of the Bay of Fundy so the geographic extent of vegetation is considerable. In addition to attached vegetation, estimates were made of stranded wrack (detached fragmented algae). Recent studies by personnel of the St. Andrews Biological Station in New Brunswick indicate that biogenous decay of standard wrack may form a large source of dissolved and particulate organic carbon, the latter a major food supply for the commercially important sea scallop.

In addition to the CIR photography taken with a Zeiss RMK camera from a twin-engined Piper Aztec, ground truth data of attached algae and wrack densities were also obtained. The algal standing crop was classified according to density from the photographs. The resulting polygons were digitized and their areas were calculated automatically by a geographic information system (GIS).

### Shorezone Classification

Color infrared photography (CIR) flown at low tide, was also used in Passamaquoddy Bay to assess the value of this film for shore-zone classification. Ground truth information was collected at the time of photography. The interpreted results were digitized on a GIS and reproduced as a colored map on a pen plotter. Because CIR is sensitive to water content, its use made the differentiation of shorezone types considerably more precise than with the use of other photographic films (MRMS, 1982).

The success of this particular project indicated the predictive potential of this technique. The clams, for example, are found in greatest abundance associated with a specific type of shorezone substrate. These areas could be relatively easily and rapidly identified over large geographic areas.

A video camera was also used for this project. Although lacking the resolution of CIR, it provided a rapid and cheap overview suitable for aquacultural site assessment, contingency planning, and the location of subsurface features.

### Monitoring of Clam Fishery

A designated clam fishing area in Nova Scotia was surveyed from various altitudes (1,000 - 3,000 feet) using color infrared film in a Wild RC-8 camera mounted in a Piper Aztec. The project was designed to test the effectiveness of aerial photography as a means of assessing fishing effort and also as a surveillance technique because the fishery is subject to periodic closure as a result of paralytic shellfish poisoning (PSP). In this area of Nova Scotia the fishery is a manual rather than a mechanical operation. Clam holes dug by fishermen were identified on the aerial photographs taken at 3,000 feet (1:6,000 scale) for at least two days after their excavation, i.e. four tidal cycles in this region of Canada. The footprints of the fishermen were recognized easily and the recreational and commercial fishery areas also could be differentiated.

**Oil Spill Detection and Monitoring**

An oil spill dispersant trial held offshore Halifax, Nova Scotia in 1983 demonstrated the effectiveness of an airborne remote sensing "package" as a means of detecting an oil spill and of monitoring its movements and the effects of various types of oil dispersants (Ripley and Goodman, 1984). Other marine pollutants potentially could be located and monitored in a similar manner.

The sensor "package" was mounted in and on a Piper Aztec and included the following:

1. Zeiss RMK camera (9 X 9 inches) using color negative film.
2. Vinten camera (70 mm) using black and white film filtered to record only ultraviolet radiation.
3. Low light level television camera also filtered to record UV radiation.
4. Forward looking thermal infrared scanner (FLIR).

The field of view of the externally mounted FLIR sensor was controlled from inside the aircraft by a joystick. Its signal was recorded on conventional video allowing real time viewing. The signal also was recorded on a normal video recorder for later play back.

The use of a multiple sensor "package" had a number of advantages: the standard aerial photographic cameras recorded data for later interpretation and analysis; the LLLTV and FLIR provided "real time" information. The difference in the ultraviolet return from oil versus water enabled the LLLTV to locate the oil slicks. The FLIR provided an indication of the thickness of the oil [thicker oil appears colder (darker gray) in the imagery] in addition to providing, with its scanning capability, a wide search field to locate the slick at a range up to 10 miles.

A similar, relatively inexpensive and portable remote sensing "package", could form an important component of contingency plans in the Caribbean. Appropriate aircraft are in plentiful supply.

**Red Tide Detection**

Under certain hydrographic and meteorological conditions micro-algae multiply at such a rate that the water is discolored by algal pigments, hence the term "red tide". In the Atlantic region of Canada (and elsewhere), these algal blooms are associated with outbreaks of paralytic shellfish poisoning (PSP) (Dale and Yentsch, 1978; White, 1980). As with ciguatera poisoning in tropical regions the responsible organism is a dinoflagellate (*Gonyaulax excavata* ) in the case of PSP and *Gambierdiscus toxicus* in the case of ciguatera (De Sylva, 1979). Both produce neurotoxins which are a serious health hazard to man and which can have a significant economic impact resulting from loss of marine resources, consumer wariness or a decline in tourism — key components in both Atlantic Canada and the Caribbean.

In the Passamaquoddy region of the Bay of Fundy the algal blooms have been located with the aid of aerial color positive film. It is possible that with an increase in knowledge of the ecological factors which precipitate the blooms in conjunction with aerial surveillance, the presence of the "red tides" could be accurately predicted and their geographic extent monitored.

**Fishing Effort Assessment and Surveillance**

The American lobster (*Homarus americanus*) is economically the most important species in the eastern Canadian fishery. Little information is available, however, on either the pattern of distribution of lobster fishing effort or lobster buoy (hence trap) density. In addition to interviewing fishermen, two remote sensing techniques were developed to collect this information.

The first technique involved visual scanning by airborne observers and the second involved aerial photography. In the latter case aerial photographs were taken using a color positive film in a Zeiss RMK camera mounted in a Piper Aztec. Various altitudes were flown from 3,000 to 5,000 feet giving photographic scales from 1:6,000 to 1:10,000. The location of the interpreted buoys were digitized and mapped in relation to bathymetry and the coastline, with the aid of a GIS and plotter. Accurate geo referencing was achieved relatively easily inshore, the major fishing zone, because of the presence of land reference points on the photographs. Offshore buoy locations relied on LORAN C data directly reproduced on the film and the matching of adjacent photographs in the area of forelap and sidelap.

A series of test flights, in different locations and under different weather conditions and sea states, identified 3,500 feet as the optimum altitude for this technique of buoy location. However, because of the costs involved in flying large geographic areas at this altitude, this type of aerial assessment and surveillance probably will be reserved for irregular flights in problem fishing areas (Pringle and Duggan, 1983).

Aerial photography also has been used to monitor the herring fishery in the Gulf of St. Lawrence. Accurate counts were made of the gillnets which are used in this area, their size, and distribution (Messieh *et al.*, 1981). Seal census using aerial photography also are flown regularly in Atlantic Canada.

**Waste Disposal, Shoreline Erosion and the Lobster Fishery**

Planned alterations to coal mining waste sites in Cape Breton Island (Nova Scotia) required a method for mapping the potential impact of the changes on coastal erosion and on the inshore lobster fishery.

Interpretation of historic aerial photography provided a series of coastline traces for four dates over a period of thirty years. The inshore area then was photographed using a Zeiss RMK camera and color positive film. Lobster buoy locations were interpreted as described in the previous case study. Lobster buoy locations and the rate of coastline erosion then were digitized and mapped with the aid of a GIS and plotter. The possible influence of proposed waste sites on coastal erosion patterns and on the inshore fisheries will be assessed in relation to this accurate baseline information (Rowley *et al.*, 1986).

A coastal conservation study carried out on the south and west coasts of Barbados in 1984 similarly used historic and current aerial photography to assess coastline erosion (Hunter and Associates *et al.*, 1984). The intensity of development in the coastal zone has caused marked beach erosion due to the destruction of beach vegetation and inshore fringing coral reefs. Because beaches are a major tourist attraction in the Caribbean, such erosion has serious economic implications.

## THE FUTURE

Aerial photography has an important role in marine resource management as indicated by the previous case studies. The inexorable tide of remotely sensed imagery from space will complement this airborne acquired information. The increasing availability of micro-based geographic information systems interfaced with digital analysis systems will permit the integration and analysis of these variously collected data sets. Independently operated geographic information systems will communicate within wide area networks and permit the rapid evaluation, manipulation, and dissemination of diverse data and information of interest to resource managers.

A sensor of particular interest to the fishing community is the Coastal Zone Color Scanner (CZCS) aboard the Nimbus 7, which was launched in 1978. The CZCS measures ocean color from solar energy reflected from the sea surface. Ocean color boundaries can be identified and related to chlorophyll and nutrient rich water, upwellings etc. These transition zones are major feeding grounds for pelagic species such as the albacore. Maps of the ocean color boundaries were transmitted to Pacific tuna fishermen by radio facsimile. In spite of the CZCS sensor being unable to penetrate cloud, tuna fishermen claim the use of the satellite information reduced the search time by 20 percent, particularly when the CZCS data was combined with sea surface temperature data from the Advanced Very High Resolution Radiometer (AVHHR) aboard a U.S. Navy Satellite (Laurs *et al.*, 1984; Montgomery *et al.*, 1986). The CZCS was turned off in June of this year but, because of its success, at least two ocean color imagers are scheduled for launching as commercial, rather than experimental, projects (Anon, 1985):

1. A wide-field Ocean Color Imager (OCI) is planned for Landsat-6, scheduled for launch in 1988.
2. Another OCI equipped satellite, NOAA-K, is scheduled for launch in mid 1990.

Portable shipboard computers are being developed to process data for both Landsat-6 and NOAA-K in near real time.

Two other ocean sensors also will aid maritime industries including fisheries:

1. TOPEX (Topography experiment): An altimeter will measure wave height to an accuracy of 2 inches from a height of 800 miles. Launch date is 1991.
2. NROSS (Navy's Remote Ocean Sensing System): A scatterometer will map the winds that drive many of the ocean currents. Launch date is 1990.
3. RADARSAT: A scatterometer, SAR (synthetic aperture radar), AVHRR, and optical sensors as well as the emphasis on realtime throughput of data will make this satellite well suited to operational meteorology and oceanography.

Information from these two sensors will be a significant aid to navigation and the safe location of ocean structures and ocean disposal sites. The safety of hazardous waste disposal on the seabed is dependent on a thorough understanding of currents which may carry leaked material to fishing grounds and coastal areas.

Advances in airborne sensors are equally as spectacular. They are now capable of scanning in the visible, infrared, and radar portions of the electromagnetic spectrum. For example, the Multispectral Electro-Optical Imaging Scanner (MEIS) (Till *et al.*, 1983), the Programmable Multispectral Imager (PMI), the Synthetic Aperture Radar (SAR), and the Side Looking Airborne Radar (SLAR). Also of note is the recent development of the Fluorescent Line Imager (FLI ) used primarily to detect chlorophyll fluorescence (Borstad *et al.*, 1985). The resolution of these sensors, however, is still not comparable to that obtained by classical aerial photography.

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