# Remote Sensing for Fisheries Management:
# Prospect and Promises

NIELS WEST
Geography and Marine Affairs
University of Rhode Island
Kingston, Rhode Island 02881

KIM RICHARDSON
LANDSAT Remote Sensing Center
Graduate School of Oceanography
University of Rhode Island

JIM GRIFFIN
Graduate School of Oceanography
University of Rhode Island

FRED J. TANIS
Environmental Research Institute of Michigan
University of Michigan
Ann Arbor, Michigan

Civilian remote sensing capability currently consists of four types of platforms: LANDSAT, TIROS-N (now referred to as NOAA), NIMBUS and GOES; each is flown in a different orbit and each mounted with one or more sensors (Table 1). Most sensors and all of those we discuss base their image system on passive as opposed to active energy. Passive energy refers to reflected and emitted solar energy. Active systems consist of electromagnetic energy transmitted by the satellite and returned to a sensor mounted on the satellite as it passes over the earth. Only a portion of the emitted and reflected energy falls within the visible band, although future technology will increasingly utilize the electromagnetic bands on both sides of the relatively narrow visible spectrum.

Each sensor is capable of surveying from four to seven electromagnetic bands. The resolution of the images varies greatly, from approximately 0.25 acre for the now defunct Thematic Mapper (TM), to approximately 9 $km^2$ for the GOES system. The resolution of the images is in part a function of the altitude of the platform and in part a function of the technology utilized. In general, the higher the altitude the lower the resolution and cost of data acquisiton and processing. The costs of obtaining the data are of great significance where images must be obtained on a daily basis. Similarly, the greater the resolution the more computer processing capability and/or the longer it will generally take to analyze this information. For groups in developing countries wishing to establish receiving stations of their own, this is an important consideration, especially if fast turn around time is desired. In addition, the availability of images varies as well. Due to its orbit the repeat overflight coverage for LANDSAT is every 18 days while the NOAA satellites repeat the exact same effective field of view of the earth every 12 hours. The earth footprint size for each of the sensors also differs. The GOES satellite orbits the earth at a distance of 23,000 miles and surveils the complete hemisphere (full disk) while the LANDSAT system is capable of only surveying 185 m$^2$ in each scene or image.

Table 1. Satellite comparisons

| Name | Sensor | Coverage | Channels (No.) | Surface Resolution (km) | Swath Width (km) |
|---|---|---|---|---|---|
| NIMBUS 7 | CZCS | 12 h | 5 | 1 | 1566 |
| TIROS N | AVHRR | 12 h | 4 | 1 | 2240 |
| NOAA | AVHRR | 12 h | 5 | 1 | 2240 |
| GOES | SMR | h | 2 | 8 | Disk |
| LANDSAT | MSS | 18 d | 4 | 129 | 185 |
| LANDSAT IV | TM | 16 d | 7 | 48 | 185 |

Until recently, the information was temporarily stored onboard until the satellite was in a position to forward it to one of several receiving stations located in the U.S. and lately on other continents. Information is transmitted in digital form as the satellite flies over the window of a given station. The digitized information is then forwarded to one of several processing centers where certain editing and formatting functions are executed before information becomes publicly available. If the receiving station has the capability of processing the information directly before it becomes archived by the U.S. satellite processing centers located at Goddard in Maryland and the EROS center in South Dakota (Cornillon, 1982), the availability of the data can be as short as 12 hours or less. Once the data are archived, however, current retrieval can be as long as 1 year.

Each satellite system has unique design capabilities, briefly summarized for each system below, which are important to the fishery scientist, manager or plant operator who may use this information to improve and increase fisheries production.

LANDSAT Multispectral Scanner.--As satellite technology improves, both quality and the quantity of the satellite and sensors will increase. Considerable expansion of the capabilities has already taken place during the past decade, where civilian applications have been possible. The LANDSAT system is the oldest and the one with the widest range in applications. Originally intended to surveil land cover only, this system has increasingly been applied to coastal and nearshore marine environmental problems. The system consists of four satellites, each placed in a polar synchronous orbit such that any location on earth located between 80$^{\circ}$N latitude and 80$^{\circ}$S latitude was surveyed. Information from three of them has been archived and is still available. The first three platforms in this system had only one operational scanning sensor. The latest (LANDSAT-4) had one additional scanning sensor, with great potential for resource analysis. The early sensor is the Multi-spectral Scanner (MSS) which surveils reflectance from four electromagnetic bands varying from 0.5 to 1.1. Each of the four bands (4, 5, 6 and 7) has been selected to identify individually or in combination different types of vegetation, water, land and water interface, and cultural (built-up) features. While the primary objectives of the LANDSAT MSS system were intended to identify land cover as opposed to coastal wetlands and features within the nearshore marine environment, a number of features have been developed which have extended the surveillance beyond the terrestrial environment.

The second LANDSAT sensor was the Thematic Mapper (TM). This sensor surveils three additional bands in addition to the four MSS bands mentioned above. One of these obtains information from the visible blue portion of the electromagnetic spectrum, while the remaining two measure reflectance in the mid-infrared and thermal infrared.

AVHRR Sensor.--The Advanced Very High Resolution Radiometer (AVHRR) surveils five channels and records emitted energy primarily from the thermal infrared portion of the electromagnetic spectrum. The primary purpose of this sensor is to measure sea surface temperature and clouds. This sensor also has the capability of detecting surface water delineation based on temperature fronts. The potential value of this capability to the fishing industry is particularly important as water bodies often are associated with specific fisheries.

CZCS Sensor.--The NIMBUS-7 satellite carries the Coastal Zone Color Scanner (CZCS) which primary function is to measure chlorophyll *a* concentration in the near surface waters. The CZCS is particularly important in measuring biomass and water pollution associated with excessive nutrient or raw sewage inflow. Taken individually or in combination, the information which these satellites can provide has vastly increased our knowledge about the physical parameters of the ocean. This information is of particular importance and significance to those regions which are changing their traditional artisanal fisheries. As has been suggested by several of the plenary speakers to this conference, there are no inherent reasons why artisanal fisheries cannot and should not increasingly take advantage of this technology in getting to and finding the most productive fishing waters.

## COASTAL AND NEARSHORE MARINE REMOTE SENSING APPLICATIONS

Papers which have addressed coastal and nearshore marine applications of remote sensing can be classified as those dealing with dry land and emergent vegetation, and the nearshore marine environment located below the mean low water. Both categories share problems related to terrestrial surveillance and which are exclusive to coastal, nearshore and marine applications. The most important of these are related to the season when the image was obtained, extent of field verification and, for coastal areas subject to tidal action, the temporarily changed environment due to flooding and ebbing.

The seasonal factor is especially troublesome for identification of vegetative cover. As vegetation moves through its annual growth cycle, its reflectance value may change from light green through yellow, orange and red to brown. In coastal applications this problem, can usually be overcome by analyzing the same area over several seasons. In the case of LANDSAT, past images can often be obtained. An example of partially overcoming such a problem, without the analysis of sequential seasonal images, is Bartlett and Klemas' (1980) study. They found visible reflectance better predictors of live biomass within the canopy, compared to the red and near infrared.

For coastal and marine application, in-the-field verification of the data represents a much more difficult problem. This is related to the continually changing sea conditions and the difficulty of correlating satellite overpass with on-board identification of the phenomena being measured. Add to this the three dimensionality of the marine environment and it is clear why most remote sensing attempts have concentrated on terrestrial applications.

The final complicating factor concerns the extent to which the "canopy geometry" of the coastal emergent vegetation has been changed due to wind and/or tidal action. This term refers to the angle at which the vegetation is perpendicular to the terrestrial surface. If the vegetation is flattened by wind or if it is waterlogged, more of the underlying soil or water (depending upon tidal cycle) will be exposed and may significantly change the reflectance value and the signature of the pixel (picture element) as the satellite makes its overpass. The pixel refers to the smallest geographical unit from which information can be measured and is directly related to image resolution. In the context of canopy geometry, Carter and Anderson (1972) found that the vertical orientation of the leaves of Spartina patens resulted in lower reflectance in the green, red and dark red bands. Nonetheless, Klemas et al. (1975) in a study of Delaware Bay, succeeded in correctly identifying S. alterniflora with a reliability of 97.5%.

Emergent Vegetation.--LANDSAT MSS information has been utilized to identify wetland grasses, nearly all in mid-latitude wetlands (Bartlett, 1977; Bartlett and Klemas, 1980, 1981; Carter and Anderson, 1972). Byrne and coworkers (1981) combined information from both LANDSAT and the meteorological satellites and succeeded in identifying four ecologically important components of an Australian (subtropical) marshland. Sobur and his collaborators (1978) working in Sumatra identified coastal wetlands, rapidly developing shoals and islands as well as the colonization by mangroves and primary and secondary swamp forest.

Coastal Land Cover Studies.--Several studies in tropical and mid-latitude environments have identified residential developments in the coastal zone. Klemas and Bartlett (1976), again utilizing LANDSAT and SKYLAB images, analyzed the distribution of coastal land uses in the Delaware Bay area. Others have used conventional aerial photographic images in making population estimates in residential areas in the U.S. (Kraus et al., 1974) and in urban settlements in Hong Kong (Lo, 1979).

Although these studies fall more closely in the category of conventional LANDSAT remote sensing applications, they are of potential value to the coastal planner responsible for the development of port facilities including fish processing and refrigeration plants. As was mentioned earlier in this conference, too many studies have emphasized a very narrow aspect of fishery development. These studies usually fail to look at such socio-environmental impacts comprehensively. Thus, upgrading an artisanal fishery, whether through cooperatives or the introduction of full commercial fisheries, is likely to result in considerable onshore impacts. Such developments often result in the degradation of productive marshlands and/or agricultural lands, both scarce resources in developed and developing countries. These environmental changes can easily be monitored using LANDSAT.

Most studies have been conducted in mid-latitude environments. There is good reason to believe that reliable and cost effective studies can be undertaken in tropical and subtropical environments, fully recognizing that these technologies would have to be adopted to the specific conditions prevailing within the regions where the information is being utilized.

## NEARSHORE REMOTE SENSING

Studies dealing with the nearshore marine environment can be divided into two groups, one which surveils reflected energy from materials floating on the surface, or identifying characteristics of the surface water, and one which, under certain circumstances, may identify features within the water column sometimes extending to the bottom.

Unfortunately, this division is by no means ironclad as floating materials may not be limited to the surface, but may occupy part or all of the water column. The potential value of LANDSAT and other surveillance sensors to identify pollutants, both organic and inorganic, has long been recognized. Deutsch and Estes (1980) using a contrast enhancement procedure succeeded in reassigning individual pixels in proportion to the area covered by that brightness level. In that same study, they were able to identify floating oil caused by natural oil seeps in the Santa Barbara Channel.

The identification of marine features is much more complicated compared to terrestrial surveillance as water absorbs, reflects and re-emits electromagnetic energy at different wavelengths. This makes identification of specific features much more difficult. To partially overcome this problem, researchers have undertaken comparative studies with platforms varying in elevation from a few feet to those mounted on satellites. Most of these studies show promise suggesting that elevation in and by itself may not act as a significant obstacle to utilize satellite mounted sensors.

Besides identifying oil (Klemas, 1972), LANDSAT has been used to identify algae blooms (Munday and Zutbkoff, 1981; Strong, 1974; Jensen, 1983) and sewage outfall plumes (Johnson et al., 1979) which may be important indicators of pending environmental degradation. Stumpf and Strong (1974) suggested that the near infrared MSS band 7 (.8-1.1 um) identified a large oil slick located off Assateague Island, Virginia. Band 7 is sensing longer wavelength which compared to the shorter wavelength tends to better reflect surface features. Unfortunately, this study was not field verified, nonetheless, both authors estimated the magnitude of the spill, which was based on an assumed thickness of 1.0 um, to total almost 53,000 gallons.

A few experimental studies have tried to identify commercial shipping (McDonald and Lewis, 1978; Anderson, 1978). The principal problem here relates to the size of the vessel, existing sea conditions and frequency of data coverage. To identify vessels utilizing existing technology in terms of resolution, each vessel would have to be in excess of 300 feet and/or must be underway, because it is the wake of the moving vessel that is being surveiled. Part of the problem associated with navigation surveillance relates to the wave conditions as these tend to destroy the wake of the vessel.

Kelp has long been important in its own right as a base of algin, a food thickener. Although kelp and fisheries may only be partially correlated, the distribution of certain species of kelp may be correlated with the densities of certain shellfish, notably abalone, besides providing a very important fishery habitat. Finally, the harvesting of seaweed has been cited as a potential source of biofuel either in the form of gas or alcohol. Research efforts have recently been undertaken to map the quality and quantity of kelp and the extent to which it has undergone change due to storms and high effluent loadings. It is not surprising, therefore, that remote sensing has been used to measure this resource. Jensen et al. (1980) successfully identified giant kelp, _Macrocystes pyrefera_, in Goleta, California. These researchers found that healthy _M. pyrefera_ had a spectral signature similar to terrestrial brown vegetation. Specifically, it reflects between 60 and 70% of the incident radian flux in the region between 0.7 and 1.1 um. Since water absorbs most of the infrared radiant energy in this region, the areas with high concentrations of _M. pyrefera_ were clearly identified.

_Remote Sensing of Benthos and Water Column Parameters_.--A potentially more valuable application of remote sensing technology in a marine environment concerns the characteristics of the water column and bottom. Several studies have addressed ocean and nearshore circulation as surveilled indirectly by the distribution of turbidity (Rouse and Coleman, 1976; Klemas et al., 1973; Kriticas et al., 1974; Szekielda et al., 1972; Feeley and Lamb, 1979). Some of the most effective studies have looked at river plumes and deltas (Finley and Baumgarter, 1980; Dufus and Press, 1981), which may be of particular importance for purposes of identifying warm core rings and cold water upwellings including fishery habitats in the nearshore marine environments. Although several studies have looked at the bio-chemical composition of seawater and its electromagnetic reflectance, including salinity (Khorram, 1982), and particulate iron (Ohlhorst and Bahn, 1979), these efforts have been highly experimental and not generally ready for direct application to practical problems.

A few studies have attempted to utilize remote sensing directly in fisheries resource identification and location (Klemas et al., 1978; Lasker and Pelaez, 1981). These studies have emphasized associated phenomena such as high chlorophyll concentrations (Cornillon, 1982; Johnson, 1978) or surface currents as these transport eggs and larvae into and out of estuaries (Klemas et al., 1980). In addition, some preliminary studies indicate very high concentrations of fish fry and eggs along convergent water fronts. Finally, temperature fronts may be important indicators of water masses within which specific schooling fish may predominate (Klemas et al., 1978).

The last major category, where remote sensing technology has been used to identify processes of potential utility to coastal zone managers, and physical and biological oceanographers, concerns erosional processes (Welby, 1978). Some work has been done dealing with wave spectra in the nearshore marine environment with potential significance to the development of shore protection measures, coastal hazard planning, fisheries and coastal management. Most of these rely on the CZCS (Lohman and Van der Piepen, 1981).

## CONCLUSION

It should be clear that the type of work currently conducted in the coastal nearshore marine environment, although quite limited in comparison to terrestrially based remote sensing work, spans a very wide range of phenomena and processes. Furthermore, while most of these studies are limited in scope, spatially and temporally, they are of potential significance for both developed and developing countries interested in making greater use of their coastal resources with minimal socio-environmental impacts.

## ACKNOWLEDGMENTS

The authors wish to extend their appreciation to the President of the University of Rhode Island Foundation, Mrs. Blanche Murray, who provided both financial and moral support at a critical stage in the research and which enabled completion of the project.

## LITERATURE CITED

Anderson, A.C. 1978. Remote sensing in sea search and rescue. Remote Sens. Envir. 7: 265-271.

Bartlett, D.S. and V. Klemas. 1980. Quantitative assessment of tidal wetlands using remote sensing. Envir. Mgmt. 4 (4): 337-345.

_____ and _____1981. In situ spectral reflectance studies of tidal wetland grasses. Photogram. Eng. Remote Sens. 47 (12): 1695-1703.

_____, _____, R.H. Rogers and N.J. Shah. 1977. Variability of wetlands reflectance and its effect on automatic categorization of satellite imagery. Proc. Am. Soc. Photogram. Eng., Annual Meeting, Wash., D.C. 70-89.

Byrne, G.F., K. Dabrowska-Zielinska and G.N. Goodrick. 1981. Use of visible and thermal satellite data to monitor an intermittently flooding marshland. Remote Sens. Envir. 11 (5): 393-399.

Carter, V.P. and R.R. Anderson. 1972. Interpretation of wetlands imagery based on spectral reflectance characteristics of selected plant species. Proc. Am. Soc. Photogram. Eng., Ann. Meeting, Wash., D.C. 580-595.

Cornillon, P. 1982. A guide to environmental satellite data. U.R.I. Graduate School of Oceanography. NOAA/Sea Grant.

Deutsch, M. and J.E. Esks. 1980. Landsat detection of oil from natural seeps. Photogram. Eng. Remote Sens. 46 (10): 1313-1322.

Dufus, H.J. and M.J. Press. 1981. Note on an extension of the Fraser River plume. Can. J. Remote Sens. 7 (2): 134-146.

Feeley, R. and M. Lamb. 1979. A study of the disposal of suspended sediment of the Fraser and Skagit Rivers into northern Puget Sound using LANDSAT imagery. U.S. Pacific Marine Lab EPA 600.7/79/165, Seattle, Wa.

Finley, R.J. and R.W. Baumgarter, Jr. 1980. Interpretation of surface water circulation Aransas Pass, Texas, using LANDSAT imagery. Remote Sens. Envir. 10: 3-22.

Jensen, J.R. 1983. Biophysical remote sensing. Ann. Assoc. Am. Geog. 73 (1): 111-132.

_____, J.E. Estes and L. Tinney. 1980. Remote sensing techniques for kelp surveys. Photogram. Eng. Remote Sens. 46 (6): 743-755.

Johnson, R.W. 1978. Mapping of chlorophyll a distributions in coastal zones. Photogram. Eng. Remote Sens. 44 (5): 617-624.

_____, R.M. Glasgow, I.W. Duedall and J.R. Proni. 1979. Monitoring the temporal dispersion of a sewage sludge plume. Photogram. Eng. Remote Sens. 45 (6): 763-768.

Khorram, S. 1982. Remote sensing of salinity in the San Francisco Bay Delta. Remote Sens. Envir. 12: 15-22.

Klemas, V. 1972. Detecting and measuring oil on water. Instrument. Tech. 19 (9).

_____ and D.S. Bartlett. 1976. Skylab and ERTS-1 investigations of coastal landuse and water properties in Delaware Bay. Prog. Astro-Nautics Aeronautics No. 48.

_____, _____ and W.D. Philpot. 19789. Remote sensing of marine fisheries resources Proc. ONR Symp. Adv. Concepts in Ocean Measurements. B.W. Barouch Inst., Univ. of S.C.

_____, _____ and _____ 1980. Remote sensing as a technique for synoptic inventories of fisheries resources. Proc. 5th Biennial Int. Est. Res. Conf., Univ. of GA. Estuarine pespectives. Academic Press, New York, N.Y.

_____, _____ and R. Rogers. 1975. Coastal zone classification from satellite imagery. Photogram. Eng. Remote Sens. 41: 499-513.

_____, J.F. Borchardt and V.M. Treasure. 1973. Suspended sediments observations from ERTS-1. Remote Sens. Envir. 2: 205-221.

Kraus, S.P.T., L.W. Senger and J.M. Ryerson. 1974. Estimating population from photographically determined residential land use types. Remote Sens. Envir. 3: 35-42.

Kritikas, H., L. Yorinks and H. Smith. 1974. Suspended solids using ERTS-A Remote data. Remote Sens. Envir. 3: 69-78.

Lasker, R. and J. Pelaez. 1981. The use of satellite infrared imagery for describing ocean processes in relation to spawning of the northern anchovy (*Engraulis mordax*). Remote Sens. Envir. 11 (6): 439-453.

Lo, C.P. 1979. Surveys of squatter settlements with sequential aerial photography - A case study in Hong Kong. Photogram. 35: 45-63.

Lohman, P. and Van der Piepen. 1981. Evaluation of ocean bottom features from ocean color scanner imagery. Photogram. 36 (3): 81-89.

McDonald, M.J. and A.J. Lewis. 1978. Ship detection from LANDSAT imagery. Photogram. Eng. Remote Sens. 44 (3): 291-301.

Munday, J.C., Jr. and R.K. Zutbkoff. 1981. Remote sensing of dinoflagellate blooms in a turbid estuary. Photogram. Eng. Remote Sens. 47 (4): 523-531.

Ohlhorst, C.W. and G.J. Bahn. 1979. Mapping of particulate iron in an ocean dump. Photogram. Eng. Remote Sens. 45 (8): 1117-1122.

Rouse, L.J. and J.M. Coleman. 1976. Circulation observations in the Louisiana Bight using LANDSAT imagery. Remote Sens. Envir. 5: 55-66.

Sobur, AS., M.J. Chambers, R. Chambers, H.S. Damopolii and A.J. Hanson. 1978. Remote sensing applications in the southeast Sumatra coastal environment. Remote Sens. Envir. 7: 281-303.

Strong, A.E. 1974. Remote sensing of algal blooms by aircraft and satellite in Lake Erie and Utah Lake. Remote Sens. Envir. 3: 99-107.

Stumpf, H.G. and A.E. Strong. 1974. ERTS-1 views an oil slick. Remote Sens. Envir. 3: 87-90.

Szekielda, K.H., S.L. Kupferman, V. Klemas and D.F. Polis. 1972. Element enrichment in organic films and foam associated with aquatic frontal systems. J. Geophy. Res. 77: 27.

Welby, C.W. 1978. Application of LANDSAT imagery to shoreline erosion. Photogram. Eng. Remote Sens. 44 (9): 1173-1177.