

REVIEW OF SATELLITE APPLICATIONS TO FISHERIES

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ABSTRACT

Satellite oceanic remote sensing applications to fisheries research and fish harvesting in the U.S. are reviewed. Specific case studies are discussed to show how satellite data have been used in fisheries that are marketed as different types of fishery products. These include albacore tuna which is marketed primarily as a canned product, northern anchovy which are reduced for meal and industrial products, Pacific salmon species marketed mostly as fresh and fresh-frozen table fish, and Gulf of Mexico shrimp which are marketed mostly fresh.

INTRODUCTION

Satellite oceanic remote sensing can be a very powerful tool when used in fisheries research and in harvesting marine resources. The successes gained in experiences using satellite data in fisheries investigations and in harvesting thus far, indicate there is immense potential for expanding its utilization. Satellite remote sensing can supply environmental information, which can lead to improvements needed to ensure the effective management of marine fishery resources. It also, can provide information to detect potentially productive fishing grounds and to make improved weather and sea condition forecasts for the safety of fishermen and their vessels and equipment.

Variations in ocean conditions play crucial roles in causing natural fluctuations of fisheries resources and their vulnerability to catch. Comprehensive information on the changing ocean, rather than on average ocean conditions, is needed to effectively manage many stocks of living marine resources and to efficiently harvest them.

The strength of satellite remote sensing lies in the ability of spacecraft sensors to monitor ocean variability with the combined advantages of large scale synopticity, high spatial resolution and frequent repeatability. Each of these characteristics is prerequisite to understanding the effects of ocean variability on fishery resources.

Despite its strengths, satellite remote sensing has weaknesses, chief of which is the capability of sensors to

measure only the surface skin or uppermost layer of the ocean. In addition, most present sensors provide useful data only in cloud-free areas. The application of satellite remote sensing to fisheries has also been hampered by difficulties in obtaining satellite data, the lack of affordable systems to process it, and by a shortage of trained people needed to conduct research and development and education of fisheries users. However, recent advances in the capabilities of data-processing systems and improved training opportunities in satellite oceanography, offer promise for the future.

In this manuscript, after a brief over-view of satellite data used in fisheries, experiences are summarized from marine fisheries investigations which have utilized satellite data. Specific examples have been selected to show how satellite data have been used in fisheries that are marketed as different types of fishery products including: albacore tuna which are marketed primarily canned, chinook and coho salmon which are sold fresh, northern anchovy which are reduced for meal and industrial products, and Gulf of Mexico shrimp which have several types of markets.

SATELLITE DATA USED IN FISHERIES

Satellite measurements that have been used in fisheries applications are: ocean temperature and color and ocean wind stress. Most fisheries research studies and operational uses of satellite sea surface temperature (SST) measurements have utilized data from thermal infrared sensors onboard the TIROS polar-orbiting meteorological satellites. Some have also used infrared data from geostationary satellites. However, only a very limited number of attempts have been made to apply ocean temperature measurements made by microwave instruments. The Coastal Zone Color Scanner (CZCS) on the Nimbus-7 satellite provided color measurements from space from early 1979 to about mid-1985. The excellent ocean color data from the CZCS have probably been more valuable for fisheries uses than any other ocean measurements made from space. There has been very limited success in using Landsat color imagery in fisheries studies. The scatterometer (SASS) aboard the Seasat-A satellite furnished data which demonstrated the importance to fisheries of high resolution

surface wind stress measurements from space. Satellite wind stress measurements can be used to calculate ocean surface layer transport, which controls the distribution of larval stages and the subsequent recruitment and harvests of many marine fishes and shrimps. Satellite measurements of ocean winds can also be extremely valuable in the detection and forecast of weather and sea conditions hazardous to safety at sea.

EXAMPLES OF SATELLITE APPLICATIONS TO FISHERIES

Albacore Tuna - A Canned Product Fishery

Albacore are highly mobile tuna which are widely distributed throughout the world's oceans. In the North Pacific Ocean, they migrate seasonally into waters off the coast of North America during July through October, where they support important U.S. commercial and recreational fisheries. Most of the albacore caught by commercial fisheries is consumed as a canned product. The distribution, availability and vulnerability of albacore off the west coast of the U.S. have been found to be related to oceanic fronts seen in AVHRR infrared and CZCS imagery (Laurs et al., 1984; Jurick, 1985; and Svejkovsky, 1987).

An investigation employing AVHRR infrared temperature and CZCS color imagery and concurrent daily commercial fishing catch records clearly showed that satellite temperature and color data can be used to define the environmental limits of the spatial distribution of fishable aggregations of albacore, and can do so more effectively than ship or aircraft data (Laurs et al., 1984). This study convincingly demonstrated that the distribution and availability of albacore off the west coast of California are related to oceanic fronts associated with coastal upwelling. Commercially fishable aggregations of albacore are found in warm, blue oceanic waters near temperature and color fronts that mark the seaward edge of waters which had been upwelled near the coast. Relatively intense fronts are favored and shoreward intrusions of warm, clear oceanic water are particularly favorable sites for albacore concentration. This study also found that during late summer, commercial concentrations of albacore several hundreds of miles offshore, were associated with oceanic boundaries noted by color fronts detectable from satellite, but without temperature gradients. The color boundaries probably distinguished the North Pacific Subtropical Front. In another study, the distribution of albacore in winter was linked to SST fronts observed in AVHRR imagery, which probably to mark the outer boundary of the California Current. (Laurs et al., 1981).

Possible mechanisms responsible for the aggregations of albacore in the vicinity of upwelling boundaries is being investigated using data from acoustic tracking of free-swimming albacore and concurrently collected oceanographic data from ships and AVHRR and CZCS data from satellites. The results suggest that albacore aggregate on the warm, clear oceanic side of coastal upwelling boundaries and avoid areas of higher productivity and forage density in upwelled waters, because they are not able to detect prey in the turbid, upwelled water. (Laurs, in prep.).

U.S. albacore fishermen make extensive use of satellite-derived fishery advisory products for determining favorable locations to fish and for safety. SST analyses based on satellite data have been routinely available for nearshore coastal waters off the U.S. west coast since 1975 (Breaker and Jurick, 1975). The format, degree of detail, and methods of dissemination of these analyses, which are in chart form, have varied over the years (Breaker, 1981). Presently, they consist of large-scale thermal boundaries which are derived from AVHRR imagery, and isotherms which are based mostly on *in situ* observations from ships and buoys. The charts are prepared twice a week and are distributed to fishermen by radio facsimile and by mail.

An AVHRR infrared sea surface temperature analysis for west coast waters, with considerable more detail is available to fishermen on a subscription basis from Ocean Imaging Company in San Diego, California. The satellite derived thermal analysis charts are distributed to fishermen at sea by radio facsimile, or photographs with false-color are disseminated by express mail or hand delivery. An increasing number of albacore and other fishermen subscribe to these ocean products because they are specially tailored to meet their needs, including high spatial resolution of surface boundary features.

To obtain satellite imagery when operating in distant water locations, some albacore fishermen have purchased low-cost systems designed for direct reception, processing and display of satellite imagery on board ship. These systems receive visual and infrared imagery with a 4 km pixel size by Automatic Picture Transmission (APT) signals directly from polar-orbiting satellites. The visual imagery is used to help avoid areas of hazardous weather, and the infrared imagery is being used to interpret SST patterns for more efficient track and fishing ground selection, in cloud-free areas.

During the early 1980's and continuing until the CZCS sensor failed, ocean color boundary charts based on CZCS imagery were utilized by U.S. west coast albacore to locate potentially favorable locations to fish (Montgomery et al., 1986). These charts were prepared and disseminated via radio facsimile in a program funded by the Jet Propulsion Laboratory and involving Scripps Institution of Oceanography and the U.S. National Marine Fisheries Service. According to surveys of fishermen, these satellite-derived ocean products were remarkably useful in locating favorable areas to fish for albacore, and could save them as much as 50% in search time.

Oregon Coho and Chinook Salmons - A Fresh Market Fishery

Chinook and coho salmon support lucrative markets as fresh fish products. An investigation is underway to evaluate the use of satellite imagery to determine the optimal time of release of salmon smolts from hatcheries on the Columbia River to correspond with ocean conditions favorable for their survival. Increasing the survival and subsequent contribution of salmon released from hatcheries to commercial and recreational fisheries can have significant economic benefit.

Up to 90% of the salmon caught in the waters off the Columbia River are released from hatcheries on the Columbia River. About 60% of the salmon caught in other areas off the Pacific Northwest are from salmon released from hatcheries on other coastal rivers and streams. While hatchery produced salmon contribute most of the fish which are harvested, the percentage of fish released that are caught is low, e.g. only about 2% for Columbia River hatcheries. About 98% of the salmon that are released suffer mortality. A major part of the mortality is believed to occur in the ocean soon after the smolts arrive there, subsequent to their release from the hatcheries (Percy, 1984).

The research is directed toward testing the hypothesis that the survival of young salmon released from Columbia River hatcheries is related to variations in characteristics of the Columbia River plume and its interactions with other oceanic processes, notably coastal upwelling. The goal of the research is to ascertain if satellite imagery can be used to determine when ocean conditions are favorable for young salmon, so that the release of the smolts from hatcheries may be timed for optimal survival. Even modest increases in survival could result in substantial increases in salmon available for harvest, and have significant economic value.

Findings thus far have demonstrated that ocean temperature and phytoplankton pigment images derived from AVHRR and CZCS data, respectively, show that the Columbia River plume has remarkable variability in coastal waters off the Pacific Northwest (Fiedler and Laurs, in review). The orientation, shape, intensity and relative temperature of the plume vary in response to coastal winds and wind-driven surface currents.

The use of satellite-derived SST distribution and frontal boundary analyses by commercial fishermen to locate potentially fruitful locations to catch fish is a further application of satellite remote sensing to Pacific Northwest salmon resources.

Northern Anchovy - A Fishery Where Catches are Reduced For Oil and Industrial Uses

Northern anchovy, *Engraulis mordax*, is a California Current fish targeted for an oil and meal reduction fishery. Like most fish species harvested for their oil and meal, the anchovy is relatively short-lived and spends its early life history stages, part of which are planktonic, in the upper mixed layer. Its spawning, early survival and recruitment to the fishery are believed to be largely controlled by ocean conditions (Lasker, 1978).

Satellite imagery has been used to investigate ocean processes in relation to northern anchovy spawning. In these studies, which were conducted for several years during anchovy spawning periods, satellite data were collected on a daily basis coincident with fine-grid oceanographic ship observations. Shipboard observations included sampling of anchovy eggs, larvae and adults as well as physical oceanographic measurements. The objectives of the

investigations were to relate variations in mesoscale SST distributions (Lasker et al., 1981) and phytoplankton pigment and SST distributions (Fiedler, 1983) with anchovy spawning, and to identify and delineate ocean processes that might be important to the survival of fish eggs and larvae. Based on satellite imagery and confirmed by shipboard observations during the studies, which were conducted in the Southern California Bight, there were distinct temperature and pigment regimes in the general geographic region where anchovy spawning normally takes place.

Lasker et al. (1981) found that anchovy avoid recently upwelled water and that the areal extent of upwelled water may be mapped using infrared satellite imagery. They concluded that the anchovy habitat for spawning in the northern part of the Southern California Bight could be defined using AVHRR satellite data. Fiedler (1983) corroborated Lasker et al. (1981) conclusion and also found that the limits of the spawning habitat in the southern part of the Bight could be differentiated using CZCS imagery. The spatial distribution of northern anchovy spawning can thus be defined by mesoscale patterns in satellite temperature and phytoplankton pigment images (Lasker et al, 1981 and Fiedler, 1983). While neither parameter alone is sufficient, both together may define the spatial distributions nearly completely. In general, the northern extent of spawning in the Southern California Bight and the offshore extent north of Santa Catalina Island are limited by cold, upwelled water advected south of Point Conception. Spawning to the south is limited by low phytoplankton pigment levels in oceanic water 20-100 km offshore rather than by temperature. However, these factors do not directly determine spawning success, but rather are indicators of oceanic conditions and processes that determine the spawning habitat.

Fiedler (1984) also demonstrated the effectiveness of using satellite AVHRR and CZCS imagery to monitor shifts in anchovy spawning habitat off California associated with the 1982-1983 El Niño warm-water conditions.

Shrimp In The Gulf Of Mexico - Mostly a Fresh Product Fishery

Surface layer transport processes play an critical role in the life cycle of shrimp. Dispersal mechanisms control the distribution of early life stages of shrimp and the transport of developmental stages from offshore waters to coastal estuarine areas in the Gulf of Mexico. Thus the recruitment and future harvest of shrimp resources are determined, in large, part by ocean surface layer transport.

Brucks et al., in prep., also see Laurs and Brucks (1985), conducted a case study to investigate whether high-resolution measurements of wind stress by the Seasat-A scatterometer (SASS) could improve estimates of surface layer and larval shrimp transport based on traditional geophysical models. The SASS- measured wind-stress field was used to calculate surface currents by the standard homogeneous, steady-state Ekman solution. The SASS approach reduces the number of assumptions involved in

the calculation of the wind-stress vector and presumably provides more accurate estimates of surface circulation. Striking spatial and temporal variability in wind-drift pattern and regions of convergence and divergence were apparent in the Gulf of Mexico using the SASS wind-stress data to calculate surface-layer transport processes. The investigators used surface-layer transport estimates calculated from the SASS data to define potential offshore areas where shrimp spawn material and very early-life stages could be rich in the plankton and coastal areas where larval and post-larval planktonic stages could accumulate prior to settling. They found that processes conducive for accumulation in the offshore regime mainly in the west central Gulf and some projections to the south, west and north. The predicted coastal areas were in close proximity to shrimp nursery grounds in Louisiana, Texas and Florida.

Brucks et al. concluded that synoptic and repetitive direct measurements of wind stress by the SASS provided a significantly enhanced capability to determine variability in wind-driven events that strongly influence shrimp recruitment processes in the Gulf of Mexico.

LITERATURE CITED

1. Brucks, J.T., T.D. Leming, and S.B. Buckett, Jr., "A model investigation using high resolution SASS wind stress measurements to derive wind surface layer transport properties in the Gulf of Mexico", In prep.
2. Breaker, L.C., "The application of satellite remote sensing to west coast fisheries", J. Mar. Tech. Soc. Vol.15, pp32-49, 1981.
3. Breaker, L.C. and F.A. Jurick., "Providing near real-time sea surface temperatures to the California north coast fishing fleet", In: Ocean 75 (Combined meeting of 1975 IEEE Conference on Engineering in the Ocean Environment and 11th Annual Meeting of the Marine Technology Society), San Diego, Calif., N.Y. IEEE, 952pp, 1975.
4. Fiedler, P.C., "Satellite remote sensing of the habitat of spawning anchovy in the Southern California Bight", CalCOFI Rep. No. 24, pp202-209, 1983.
5. Fiedler, P.C., "Some effects of El Niño 1983 on the northern anchovy", CalCOFI Rep. No.25, pp53-58, 1984.
6. Fiedler, P.C. and R.M. Laurs, "Variability of the Columbia River plume observed in visible and infrared satellite imagery", Remote Sensing Environ., In rev.
7. Jurick, F.A., "A comparison between North Pacific commercial albacore (*Thunnus alalunga*) catch and the satellite derived West Coast thermal boundary analysis", M.S. Thesis, Humboldt State University, Arcata, Calif., 79pp, 1985.
8. Lasker, R., "The relation between oceanographic conditions and larval anchovy food in the Californian Current: identification of factors contributing to recruitment failure", Rapp. P.-V. des Reun. Cons. int. Explor. Mer. Vol.173, pp212-230, 1978.
9. Lasker, R., J. Pelaez and R.M. Laurs, "The use of satellite infrared imagery for describing ocean processes in relation to spawning of northern anchovy (*Engraulis mordax*)", Remote Sensing Environ., Vol.11, pp439-453, 1981.
10. Laurs, R.M., "The role of water clarity in albacore aggregations in upwelling frontal areas", In prep.
11. Laurs, R.M. and J. Brucks, "Living marine resources applications", In Satellite Oceanic Remote Sensing, Ed. B. Saltzman, Adv. Geophys., Vol.27, pp419-452, 1985.
12. Laurs, R.M., R.J. Lynn, R. Nishimoto, and R. Dotson, "Albacore trolling and longline exploration in eastern North Pacific water during mid-winter 1981", NOAA Tech. Memor., NMFS-SWFC-10, 52pp, 1981.
13. Laurs, R.M., P.C. Fiedler, and D. Montgomery, "Albacore tuna catch distributions relative to environmental features observed from satellites", Deep Sea Res., Vol.31, pp1085-1099, 1984.
14. Montgomery, D.R., R.E. Wittenberg-Fay, and R.W. Austin, "The applications of satellite-derived ocean color products to commercial fishing operations", MTS Jour. Vol.20, No.2, 72-86, 1986.
15. Percy, W.G., "The influence of ocean conditions on the production of salmonids in the North Pacific, a workshop", Oregon State Univ., Sea Grant College Program, ORESU-W-83-001, Corvallis, Oregon, 327pp, 1984.
16. Svejkovsky, J., "Remotely Sensed Ocean Features and Their Relation to Fish Distributions", In: Organisms As Indicators, Eds. G. Kleppel and D.F. Soule, Springer-Verlag Publishers, N.Y., pp179-197, 1987.