REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEMS:

Implications for Global Marine Fisheries

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Remote Sensing and Geographic Information Systems: Implications for Global Marine Fisheries

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ABSTRACT

During the decade of the 1990s, several major fishing countries will launch satellites with improved, next-generation ocean color sensors. This new technology, especially when combined with satellite-based estimates of sea surface temperature and geographic information systems, provides the possibility of near real-time support for the management and utilization of both pelagic and mid- to deep-water fisheries. This report reviews current state-of-the-art efforts in these areas, makes projections about anticipated uses of the new technologies in global marine fisheries, and evaluates the position of the United States relative to foreign fishing powers in the aforementioned areas.

INTRODUCTION

Historically, members of the fishing community, including both fishermen and resource managers, have used remotely sensed products in the form of either direct Advanced Picture Transmission (APT) reception or fax charts. Both products have severe limitations in the context of real-time support or management of an operational fishery. These limitations include but are not limited to poor spatial resolution, limited temperature resolution, and poor visual quality. Such shortcomings of traditional satellite support strategies for marine fisheries have been recognized by the Canadian, Russian, Japanese, Taiwanese, and Korean fishing industries. In addition, relatively little use of geographic information systems (GIS) technologies has been made by those engaged in operational fisheries or fisheries management, or by the general oceanographic community. Unfortunately, the American fishing industry has not addressed, and is perhaps unaware of, efforts by foreign-based fishermen to more effectively utilize remote sensing and geographic information systems (RS/GIS) to increase their catch-per-unit effort. Ultimately, this situation could lead to a poor competitive posture for the American fishing fleet, and make more difficult the stock assessment problem for federal and state resource managers.

At present, the U.S. fishing fleet uses antiquated remote-sensing technology and has almost no GIS capability. These deficiencies contribute to an inefficient and ineffective utilization of pelagic resources on a species-by-species basis (e.g., tuna, swordfish). Under these circumstances, those foreign fishing interests that are currently being equipped with RS/GIS technologies would be better able to utilize fisheries resources, and present U.S. stock assessment tools would probably prove inadequate to ensure the proper management of U.S. resources. Examples of RS/GIS technology are the SORPU system currently under initial sea trials by the Russian Republic of the Commonwealth of Independent States and the Salmon Early Assessment Grid (SEAGRID) under design and development by Canada.

This report provides a brief overview of such activity and attempts to accurately summarize the possible directions these efforts might take in the 1990s. It was prepared under a grant from the International Technology and Information Transfer Program of the California Sea Grant College. Space precludes an exhaustive treatment of all such efforts. Therefore, only representative results from some geographically widely distributed fisheries are discussed.

DATA SOURCES

The information presented in this report was gathered at three meetings on the present and potential use of remote-sensing/geographic information systems in support of global commercial fishing. The first meeting was held in Moscow from July 4-15, 1991 at the Space Information Service headed by Glavcenter "Ocean" (Moscow, VNIRO). This organization is responsible for satellite-directed support of worldwide fishing activity of the Commonwealth of Independent States (C.I.S.) and reports directly to the C.I.S. Minister of Fisheries. Operational fisheries oceanography, as practiced and managed in the C.I.S., developed within the framework of a set of fisheries programs conducted by a system of research institutes (VNIRO in Moscow, PINRO in Murmansk, AtlantNIRO in Kaliningrad, BaltNirkh in Riga, YugNIRO in Kerch, CaspNIRO in Astrahan, and TNIRO in Vladivostok) and fish reconnaissance departments in Murmansk, Kaliningrad, Kerch, and Vladivostok. At this ten-day meeting, meaningful information about current and future plans for satellite-directed fisheries was exchanged.

The second meeting was held at the Oceanography Department of the University of British Columbia between August 10-15, 1991. This meeting, by invitation only, focused on Canadian-Japanese fishing activity, especially in the North Pacific Ocean and Bering Sea. Canadian emphasis was on the OPEN and SEAGRID programs, both of which require the use of RS/GIS to implement the near real-time utilization and management activity required by these programs. Japanese interests focused on long-term monitoring of environmental conditions and the use of new ocean color sensors [e.g., Sea-viewing Wide Field of View Sensor (SeaWIFS), Advanced Earth Observing Satellite/Ocean Color and Temperature Scanner (ADEOS/OCTS)] in support of global Japanese fishing. In anticipation of these new technologies, the Japanese government has re-organized the Japan Fisheries Information Service Center (JAFIC).

A third meeting about second generation satellite-borne Ocean Color Sensors [e.g., Reflective Optics System Imaging Spectrometer (ROSIS); Medium Range Imaging Spectrometer (MERIS)] was held at the Joint Research Center of the Commission of the European Countries (CEC). Parts of these proceedings have direct relevance to European activities in the area of high-technology support of commercial fishing activity (e.g., CZCS European Archive and Processing System; Global Environmental Space Data Network).

HISTORICAL AND ANTICIPATED USES OF SPACECRAFT DATA IN SUPPORT OF OPERATIONAL FISHERIES

United States

Satellite data were first used in experimental support of a regional fishery in the early 1970s, but since 1975 maps of ocean thermal boundaries, based on Advanced Very High Resolution Radiometer (AVHRR) data, have been distributed to both commercial and sports fishermen (Cornillon, 1986). American tuna fleet records indicate that these thermal charts can reduce search time by 25% to 40% (Johannessen et al., 1989).

NASA and the National Weather Service (NOAA) supported a two-year fisheries demonstration program off the west coast of the United States (Laurs et al., 1984; Montgomery et al., 1986). This program used a combination of AVHRR, Coastal Zone Color Scanner (CZCS), and wind field data to help locate commercial catches of tuna, swordfish, and salmon. These results showed that ocean color boundaries which separate warm, clear oceanic water from colder, more turbid coastal water are highly preferred by albacore. Albacore and swordfish fishermen who participated in this project estimated that CZCS-derived color charts can save them as much as 50% in search time (Johannessen et al., 1989).

Other U.S. fisheries that have experimented with the use of satellite data include, but are not limited to: (1) use of Landsat data in the Mississippi Sound and off the coast of Louisiana to enhance herring catch (Kemmerer and Butler, 1977); (2) use of AVHRR data off the northeastern U.S. to catch herring (Cornillon, 1986); and (3) in the North Pacific, the Honolulu Laboratory of NOAA's Southwest Fisheries Center has used AVHRR data to study relationships between thermal structures found in the North Pacific Transition and the Subarctic Frontal Zones and the distribution and density of commercially important species (e.g., pelagic squid, salmon, and albacore) in relation to these thermal structures.

Future U.S. use of remotely sensed data in support of an operational fishery is likely to emphasize a combination of plant pigment information derived from the SeaWIFS instrument and thermal front analysis derived from the ongoing series of operational NOAA satellites delivered in near-real time to the fishing fleet. SeaWIFS is scheduled for launch in August, 1993. Thus, this combined operational scenario probably will not be implemented until sometime after mid-1994. Note, however, that because of the increased sensitivity of SeaWIFS compared to CZCS, more rigorous approaches to cloud removal and aerosol correction will be needed for SeaWIFS data than traditionally were used for CZCS data if the full potential of SeaWIFS data is to be realized by the operational fisheries oceanography community (Simpson, 1992a). This latter comment also applies to the Moderate Resolution Imaging Spectrometer (MODIS) and High Resolution Spectrometer (HIRS) instruments which are scheduled for launch in the late 1990s as part of NASA's Earth Observing System (EOS). They should provide even better spectral and spatial resolution of plant pigment and thermal features of direct relevance to the utilization and management of pelagic species than does SeaWIFS.

Relatively little support for the catch and management of nonpelagic species has been provided in the U.S. during the past decade compared to that provided for pelagic fisheries. This situation has occurred primarily for two reasons: (1) satellites generally do not provide data that are always directly relevant to nonpelagic species; and (2) the use of GIS technologies, which could be used to support nonpelagic fishing activity, has not been incorporated in any significant way into fisheries operations either by industry or government agencies. In this latter respect, the U.S. significantly lags behind other major fishing countries.

Canada

Sea surface temperature, color, and plant-pigment frontal boundaries determined from AVHRR and CZCS have been combined with airborne Platinum Resistance Thermometer, Model 5 (PRT-5) infrared sea surface temperature and optical spectrometer measurements to establish the relationships between the distribution of troll salmon fishing effort and oceanic environmental variability off western Canada (Borstad et al., 1982).

Airplane-mounted remote sensing instrumentation, such as that used by Borstad and his colleagues in their 1982 study, and aerial photography have played a much more significant role in operational fisheries in Canada than in the United States. For example, it has proven to be the most cost effective way to estimate potential salmon productivity in fresh water rivers (see Amiro, 1974; Dubois and Clavet, 1984). Aerial photographic surveys also have been used successfully to estimate fishing efforts for inshore herring (Messieh and McPherson, 1980), herring (Messieh, 1984), lobster (Canon and Maynard, 1983),and capelin (Nakashima et al., 1989).

Future Canadian efforts are likely to be directed along two main lines: (1) to develop better instrumentation and data logging-processing techniques for the aerial surveys; and (2) to utilize the SeaWIFS and AVHRR instruments in a fashion similar to the anticipated American use. Thus, it is likely that the Canadian designed Compact Airborne Spectral Imager (CASI) will play an increasingly important role in Canadian fisheries oceanography. Already CASI has been used successfully to remotely detect schools of Pacific herring (Borstad et al., 1992). Airborne systems such as CASI probably will be used in the 1990s to: (1) relate the behavior of fish to other remotely sensed parameters such as plant-pigment concentration, sediment concentration, oil slick occurrence, and water mass boundaries (e.g., Borstad et al., 1992); and (2) monitor the occurrence and movement of coastal algal blooms. Synthetic Aperture Radar (SAR) data also may be used for ice detection to support the North Atlantic cod fishery based in Newfoundland.

SEAGRID is a program sponsored by the British Columbia Salmon Troller Association, which is designed to help bridge the information gap between the fishing industry and the fisheries management of the Canadian Department of Fisheries and Oceans. SEAGRID proposes to establish a computer network within the B.C. salmon troller fleet to capture data on catch rates, stock identification, and the oceanic environment in near-real time. Two of the main problems identified by industry as adversely affecting the catch of salmon are: (1) avoiding harmful bycatch by determining the distribution of juvenile chinooks; and (2) searching for underutilized fishing opportunities before and after the current fishing season with the premise that landings quality would improve from a larger season. SEAGRID is scheduled to begin sometime in June, 1992. SEAGRID is a unique effort to develop and apply RS/GIS technologies, data assimilating oceanographic models, dynamic fish migration models, near-real time data collection, database management, and network distribution methods to the problem of the shape and size of salmon runs in British Columbia.

Commonwealth of Independent States

Satellite data and analyzed products are provided to the Commonwealth of Independent States (C.I.S.) fishing fleet by the Space Information Service, Glavcenter "Ocean"/VNIRO Moscow (Figure 1). Data from both the meteorological (METEOR) and scientific (KOSMOS) series of satellites are used, often in conjunction with shipboard observations, to prepare weekly sea surface temperature maps which are distributed to ten world ocean fishing regions of primary interest to the Commonwealth. These regions cover a total area exceeding 60 million km^2 of ocean surface (Zonov, 1990).

VNIRO still conducts about 250 research and fish reconnaissance expeditions on an annual basis from about 180 vessels. Data from these cruises are transmitted daily back to land-based research centers (e.g., VNIRO in Moscow, AtlantNIRO in Kaliningrad, TNIRO in Vladivostok) and to operational fisheries centers (e.g., Murmansk, Kerch). It is the responsibility of these various centers to analyze the combined remotely sensed and shipboard data and then to develop specific operational recommendations for each fishing region on a daily to weekly basis.

Satellite data in the visible region of the spectrum taken with multispectral scanners on the CIS KOSMOS series of satellites are used to estimate the distribution of phytoplankton biomass. Superimposed on these distributions of phytoplankton are fish catch statistics on a species-by-species basis (Zonov et al., 1992). Data from the visible spectral range also are used to provide estimates of meteorological conditions for the ten world ocean fishing regions of most interest to the C.I.S.

Use of remotely sensed ocean color data [e.g., Optical Multispectral Scanner (MSU-M) flying on KOSMOS and OCEAN satellites] in support of operational fisheries has proved successful, even though the MSU-M has limited spectral resolution (0.5–1.1 μm measured in four channels). It is anticipated that an improved ocean color sensor, the MSU-SK, will fly on the PRIRODA mission and will incorporate five channels within the spectral range 0.5–12.6 μm. After PRIRODA, an even more advanced ocean color/temperature sensor, the MSU-SK(M), is planned. This instrument will have six channels in the spectral range of 0.41– 12.4 μm, a swath width of 40° (conical scan), and a pixel size of 200 m at nadir in the visible and near infrared and of 600 m at nadir in the thermal infrared (Van Der Piepen and Döerffer, 1992). These high spatial resolution color and thermal channels will be particularly well suited to support operational fisheries.

Traditionally, the Soviet support for its worldwide operational fishery has been more sophisticated than that used in most other countries. The basic support approach involved a combination of remotely sensed and *in situ* data coupled with modeling efforts and information feedback loops from the fishing fleet to the research and operational centers required to support the fleet. Catch of non-pelagic species, such as Bering Sea flounder, for example, was optimized by tracking the 3-4°C isotherm in winter (Zonov et al., 1992). Likewise, dissolved oxygen distributions were used to successfully locate commercial schools of sardinops. Modeling always was used to produce fish catch forecasts. These models ranged from physio-statistical predictions of temperature to more sophisticated efforts which attempted to predict the distributions of temperature and salinity on the basis of a prognostic wind field (Zonov et al., 1992). As these models continue to evolve, an increasing use of multivariate techniques to improve predictive skills can

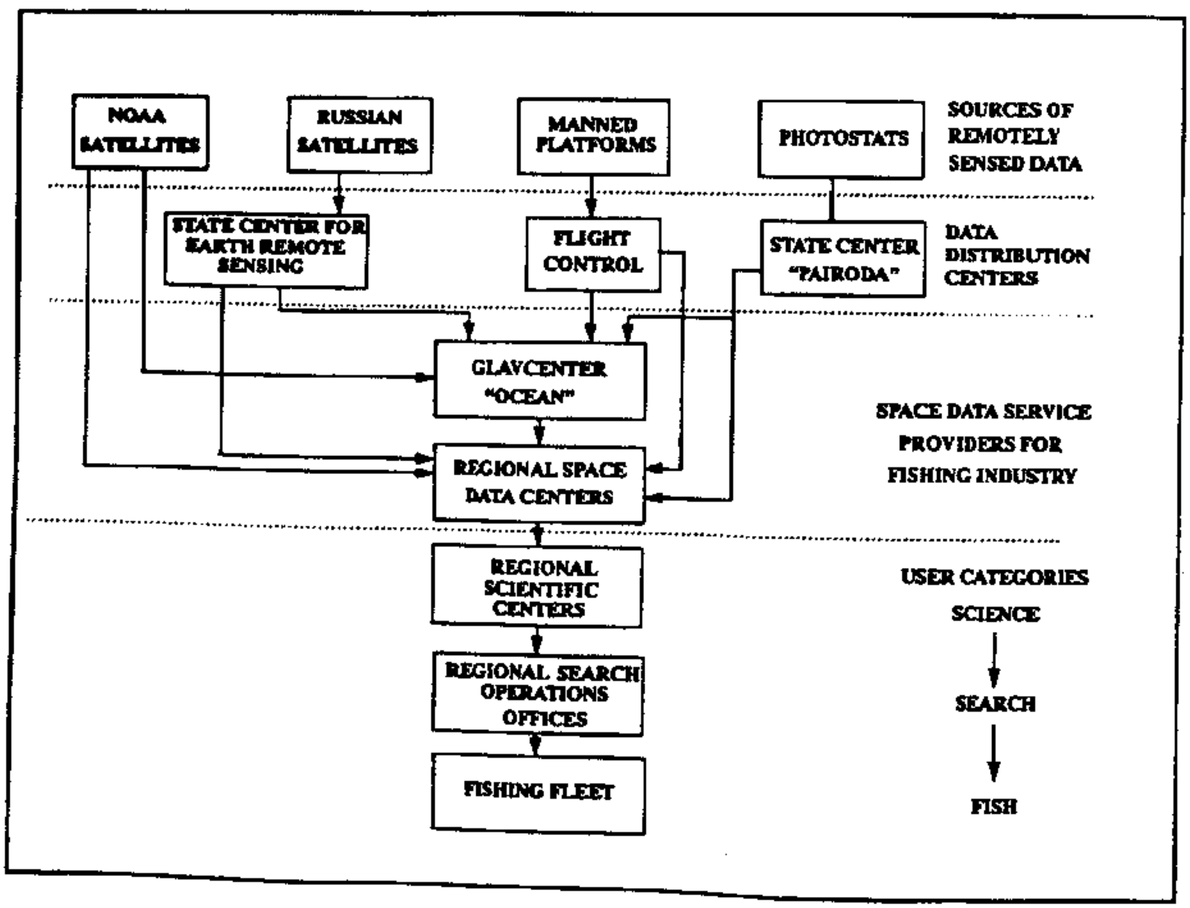

Figure 1. Conceptual diagram of the support structure for the global fishing fleet of the Commonwealth of Independent States (based on data contained in Zonov et al., 1992).

be anticipated.

More recently, efforts (i.e., SORPU-1) to integrate all the various aspects of support and prediction for operational fishing regions have been initiated by TNIRO in Vladivostok (Zonov et al., 1992). This computer-based system allows for both operational and retrospective merging and analysis of various data types relevant to an operational fishery. The SORPU-1 system (Bocharov, 1990) computes environmental characteristics and estimates their significance for a given operational fishery, estimates the catch- per-unit effort for potentially promising fishing areas, and makes short-term forecasts useful to the fishing vessel. The SORPU-1 system represents an initial effort by the Ministry of Fisheries of the C.I.S. to introduce combined RS/GIS capabilities into the operational fishing fleet. It is likely that advanced RS/GIS technology will be introduced into the entire C.I.S. fishing fleet sometime during the 1990s. Such RS/GIS systems will be used in near-real time to combine *in situ* data with plant pigment and thermal data taken with the newer satellite-borne instruments discussed above. This combination promises near optimal tactical support for the worldwide fishing effort of the C.I.S.

Japan

One of the world's four major fishing grounds is found off Japan, where waters from the warm Kuroshio Current and cold Oyashio Current merge. Approximately 31% of the total world fisheries yield is taken from these waters (Johannessen et al., 1989). This circumstance has resulted in a major, well-coordinated effort by Japan to support its fishery (Figure 2). Operational use of remote sensing occurs in three broad areas: (1) field use of portable NOAA APT receivers, which are local and land-based at Fisheries Radio Stations; (2) national coordinated support of Japanese fisheries mainly through the JAFIC; and (3) scientific experiments, involving both optical and microwave measurements, designed to provide an understanding of ocean temperature, dynamics, and sea ice (Johannessen et al., 1989).

A typical product distributed by JAFIC displays a 5-day average of sea surface temperature which includes fishing information (e.g., fishing location, amount of catch), biological information (e.g., size distribution, gonad index), and also market information (Hirano and Mizuno, 1992). Data also are provided to the Regional Fisheries Research Laboratories (RFRL) of the Japanese Fishing Agency which has responsibility for forecasting the distribution and abundance of important fisheries resources on a region by region basis.

Scientific investigations also have used remote sensing to study oceanographic variability in the Tsugaru Warm Current (Kubokawa, 1988), and it was found that quasi-periodic variability in the Tsugaru Warm Current correlated very highly with the formation of the mackerel fishing ground. This variability also has been verified by modeling efforts (e.g., Kawasaki and Sugimoto, 1988).

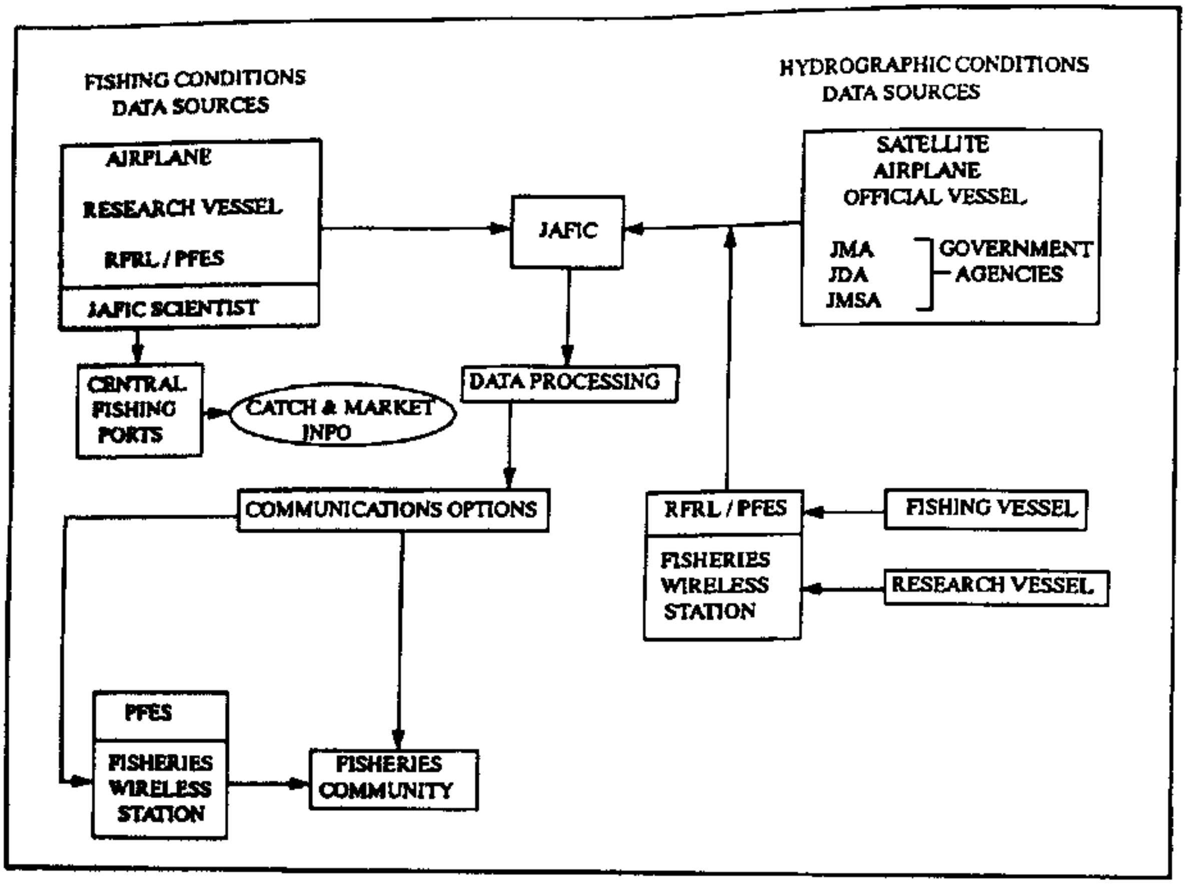

Figure 2. Overview of the support structure for the Japanese fishing fleet (based on data contained in Hirano and Mizuno, 1992).

The Japanese anticipate a restructuring of their operational fisheries support organizations somewhat along the lines of development vs. operational activity. JAFIC's capabilities will be enhanced considerably, and it will archive, analyze, and distribute biological and oceanographic data (Hirano and Mizumo, 1992). Also, some of the forecasting methods developed by RFRL will be transferred to JAFIC. This will enable RFRL to concentrate more on the development of forecasting capability using a combination of remote sensing analyses, *in situ* data, and models. The Japanese have placed a high value on the combined use of satellite-derived sea surface temperature and color/phytoplankton maps to economically locate fish. Sometime in 1995, the National Space Development Agency of Japan, NASDA, is scheduled to launch the Advanced Earth Observation Satellite (ADEOS) with core sensors like the Ocean Color and Temperature Sensor (OCTS), which is a medium-resolution color sensor with direct fisheries applications (Tanaka, 1992). The OCTS will have the same narrow-band spectral resolution in the visible range as the U.S. SeaWIFS instrument, and unlike SeaWIFS, will have the added advantage of fine thermal resolution in the infrared for a good simultaneous estimate of sea surface temperature. Unfortunately, ADEOS/OCTS will broadcast high resolution data only in the X-band. The expense of X-band reception, compared to the traditional L- or S-band data transmission used with NOAA High Resolution Picture Transmission (HRPT) data, probably will preclude the use of ADEOS/OCTS data by most other countries in support of their operational fisheries. Moreover, Japan will fly a Global Imager aboard ADEOS-II in late 1998.

France

French utilization of remotely sensed data within a fisheries context is coordinated primarily by two organizations: (1) the French Scientific Research Institute for Development and Cooperation (ORSTOM); and (2) IFREMER, a governmental agency that combines industrial and commercial activities of the French Ministry of Research and Technology and the Ministry of the Sea. Ocean color data from CZCS and sea surface temperature data from the AVHRR have been used extensively for fisheries applications in the Mediterranean Sea, the tropical Atlantic, and off the coast of West Africa (e.g., Dupouy et al., 1988). Higher spatial resolution SPOT data have been used in connection with shellfish farming near New Caledonia (Bour et al., 1986). ORSTOM also has developed a tuna forecasting model based on comparing sea surface temperature (SST) thermal structure development over a 5-week period with contemporary data. In this application both NOAA and METEOSAT data were used. Operationally, this activity supported various tuna fishing efforts off France, the Ivory Coast, and Senegal from February, 1982 to June, 1985 (Johannessen et al., 1989).

IFREMER's primary activities relative to fisheries resources include: (1) evaluation and monitoring of regional (e.g., North Sea, Antilles) and European fish stocks and their utilization patterns; and (2) encouragement of aquaculture by developing new sites and cultivation techniques for new aquaculture species (e.g., scallops, sea-breams, turbots), and providing mechanisms of technology transfer to industry and to developing countries. As an example, IFREMER has been very active in encouraging use of remote sensing among the island nations of the Pacific Basin (Loubersac, 1988).

The French also have made extensive use of the ARGOS system in support of operational fisheries activity. ARGOS is a satellite data transmission and tracking system which uses the HRPT capabilities of the NOAA weather satellites. The ARGOS system has been used to locate albacore (*Thunnus alalunga*) in the Northeast Atlantic and to study shrimp (*Penaeus subtilis* and *P. brasilienis*) on the continental shelf of French Guyana (Johannessen, 1989).

The French have had considerable interest and experience in ocean color sensors. For example, they have been heavily involved in the development of the European Space Agency's (ESA) MERIS, which will be flown on ESA's first polar platform mission (PPF-1). Presently, the French are trying to incorporate MERIS into an early-launch alternative to PPF-1 on the GLOBSAT mission (Van Der Piepen and Döerffer, 1991). Such efforts could provide the European Community with advanced ocean color capability ideally suited to support its operational fisheries well in advance of ESA's initial schedule.

Germany

Germany has made major contributions to the ESA program in support of operational fisheries through the design and building of imaging spectrometers. Two systems of particular importance are: (1) the Reflective Optics System Imaging Spectrometer (ROSIS); and (2) the Modular Optical Scanner (MOS).

MOS is an imaging spectrometer consisting of two subsystems (MOS-A and MOS-B) scheduled to fly on the PRIRODA-1 module, which will be attached to the C.I.S./MIR station in 1992 (Van Der Piepen and Döerffler, 1992). MOS-B is a 13- channel optical spectrometer (half width = 10 nm), which covers the spectral range 400–1010 nm using 128 detectors in each channel oriented perpendicular to the flight direction (Van Der Piepen and Döerffer, 1992). Because MIR has a relatively low altitude (350 km), MOS will have a swath width of only 82 km (Zimmermann, 1990), and thus MOS will not provide global coverage of ocean color. MOS, however, is important because it is likely to be the first narrow-banded ocean color sensor to be launched in the 1990s, and it will provide strong support for the development of analysis procedures for future (e.g., SeaWIFS, ADEOA/OCTS, MERIS) global ocean color datasets (Van Der Piepen and Döerffer, 1992).

Germany is also planning to launch an Environmental Monitoring Satellite (ATMOS) which will carry, among other sensors, the ROSIS. ROSIS on ATMOS is a modification of an airborne prototype imaging spectrometer designed to support ESA's MERIS system. ROSIS will have a large swath width (1460 km), a medium pixel size (250 m), and narrow band width (1.8-3.6 nm) within the spectral range 400-1050 nm (Van Der Piepen and Döerffer, 1991). Eighteen of the instrument's 100 spectral channels can be selected upon command. Both X-band and S-band transmission of data are expected, but S-band data will have reduced spatial resolution. ATMOS will have a sun-synchronous, descending orbit with an equator crossing time at 11:00 am and fly at an approximate altitude of 793 km (Van Der Piepen and Döerffer, 1992). The launch windows of MOS and ROSIS, relative to past and future intended ocean color sensors, are shown in Table 1.

Scandinavia

Danish efforts in remote sensing are particularly well suited to providing a scientific basis for the utilization and management of an operational fishery. *In situ* bio-optical measurements have been combined with remote sensing techniques, both aircraft and satellite, to monitor marine primary production (e.g., Højerslev, 1981; Nykjaer et al., 1986; Nykjaer et al., 1988). The Danish Institute of Fisheries and Marine Research has applied some of these basic research concepts to fisheries oceanography by attempting to develop relationships between primary production and the growth rates of larval fish (e.g., Kiørboe et al., 1988). The continued efforts of the Danish groups will prove especially helpful because these groups have well-known expertise in the area of bio-optical calibrations; such calibrations will be needed for the proper re-

Table 1: Past and Proposed Ocean Color Satellite Sensors

Country	Scanner	Launch Date
United States	Coastal Zone Color Scanner (CZCS)	1979
	Sea-viewing Wide Field of View Sensors (SeaWIFS)	1993
	Moderate Resolution Imaging Spectrometer (MODIS)	1998
Japan	Ocean Color and Temperature Sensor (OCTS)	1995
	Global Imager (GLI)	1998
European Space Agency	Ocean Color Monitor (OCM)	ERS-1
	Advanced Ocean Color Monitor (AOCM)	ERS-2
	Medium Range Imaging Spectrometer (MERIS)	1998
Germany	Modular Optical Scanner (MOS)	1992
	Reflective Optics System Imaging Spectrometer (ROSIS)	1995/ 1996
France	Vegetation Monitoring Instrument (VMI)	1994
	Medium Range Imaging Spectrometer (MERIS)	1996

trieval of pigment from data taken with the future generation ocean color sensors (e.g., MERIS, SeaWIFS).

Swedish use of remote sensing has been concerned primarily with monitoring the coastal zone, especially oil pollution, frontal zone, and ice zone formation. In spite of cloud cover, AVHRR data have been used successfully to locate temperature gradient fronts and relate these frontal structures to catch rates of salmon in the Baltic Sea (Johannessen et al., 1989).

Norway has made extensive and excellent use of remote sensing to protect both its wild and cultivated salmon from poisoning resulting from large algal blooms of *Chrysochromulina polylepis*. Time series of AVHRR have been used to show the development and movement of the algal blooms. This in turn has permitted the Norwegian authorities to alert its fishing community to the expanding presence of the algal blooms with enough lead time for them to tow their fishing cages out of danger. Details of this important near-real time application of remote sensing to fisheries oceanography and coastal management are given by Johannessen et al., 1988.

People's Republic of China

The People's Republic of China recently launched a series of satellites (i.e., Fengyun [Wind and Cloud, FY-1A, FY-1B]), which combine in five spectral channels properties of the American

CZCS and AVHRR sensors. The five spectral channels for FY-1B are 505, 555, 625, 875 nm, and 10.5 µm. The blue and green channels are expected to allow an analysis of global chlorophyll content at least for case-1 water, and the thermal channel will provide an estimate of SST (Van Der Piepen and Döerffer, 1992). The primary justification for the development and launch of this remote-sensing capability was direct near-real time support of the offshore Chinese fishery (Pan Delu, 1992). Future launches of fisheries-oriented satellites are planned by China through the 1990s; special emphasis will be placed on combined color/temperature sensors which can properly measure plant pigment concentration in the more turbid case-2 and case-3 waters often found off the Chinese coast (Pan Delu, 1992).

Other Nations

Several other countries have used remote sensing in some type of aquatic/fisheries application. In Zimbabwe, satellite data (e.g., LandSat TM) have been used to locate and inventory small water bodies for aquaculture and fisheries management (Kapetsky, 1987). South Africa has placed special emphasis on the use of ocean color data (e.g., CZCS) to utilize and manage the commercial fisheries of the Benguela upwelling ecosystem because the annual yield in this region is over two million tons of fish (Crawford et al., 1987). Brazil has used AVHRR-derived SST maps to locate high-yield sardine fishing grounds (Parada, 1981). Brazilian attempts to use VISSR-derived sea surface temperature maps to locate tuna in the southwest Atlantic have been less successful (e.g., Abdon, 1982, 1984). As mentioned previously, attempts to locate tuna with satellite data are most successful when a combination of temperature (e.g., AVHRR) and plant pigment/ocean color data (e.g., CZCS) are used. New Zealand has used remotely sensed data to locate major oceanic frontal structures off its coast; these have been correlated with good success to the occurrence of commercially viable tuna catches. Satellite data (AVHRR) also have been used by New Zealand to forecast yearly class strength and the variability in egg/larval survival of the snapper fishery in Hauraki Gulf (Johannessen et al., 1989).

GLOBAL DATABASES AND GEOGRAPHIC INFORMATION SYSTEMS

The material presented in this report clearly shows that a wide variety of ocean color and thermal sensors, having direct relevance for the near-real time support of operational fisheries (and other important areas such as aquaculture and agriculture), is planned for the 1990s. As a necessary consequence, careful consideration must be given to the database management, archive, product preparation, and distribution issues that will be raised by this stream of new data. Moreover, the incorporation of both historical archives and *in situ* observations into a unified, geo-referenced database will be necessary if optimal benefits are to be derived from the increased stream of spacecraft data. Two activities that are currently addressing these issues are: the Global Resource Information Database (GRID) program and the European Earthnet program. Each is described briefly below.

GRID is an activity sponsored by the United Nations Environmental Program (UNEP). Its mission is to provide timely and reliable geo-referenced information and ready access to an international GIS, which can be used to address environmental issues at global, regional, and national levels in order to bridge the critical gap between scientific understanding of environmental processes and sound management of the environment (UNEP document, undated). GRID has four main activity areas: (1) database management, including the acquisition, verification and distribution of geo-referenced environmental datasets; (2) system development activity (i.e., hardware and software system design, implementation, and testing) in anticipation of the larger environmental datasets that are scheduled to become available in the 1990s; (3) development of GIS capabilities and expertise for supporting environmental assessment; and (4) development of a GIS transfer of technology path to strengthen national capabilities.

GRID is not specifically intended to provide support for a commercial fishery. Nonetheless, GRID clearly identifies many of the technical issues that the operational fisheries oceanography community will have to address if it is to make optimal use of environmental datasets that soon will be available. This is especially important within the context of enhanced support for mid- and bottom-water fisheries using a combination of GIS technology, and both real-time and historical *in situ* data (e.g., Simpson, 1992b).

The European Space Agency and the Commission of the European Communities are jointly managing the development of an international data network, the Global Environmental Data Network (Figure 3), in anticipation of European needs, both research and operational, in response to the large number of space platforms scheduled for launch during the 1990s (Fusco, 1992). Their design goals will be implemented in three phases: (1) Phase 1 (by 1993) development of commonalities among different instruments (ERS-1, LandSat 6, NOAA-AVHRR), harmonization of services provided to the European community by a variety of suppliers, and improvement of data user-supplier interface functions; (2) Phase 2 (by 1995) multi-mission, multi-sensor operational implementation and validation of data handling protocols and newly

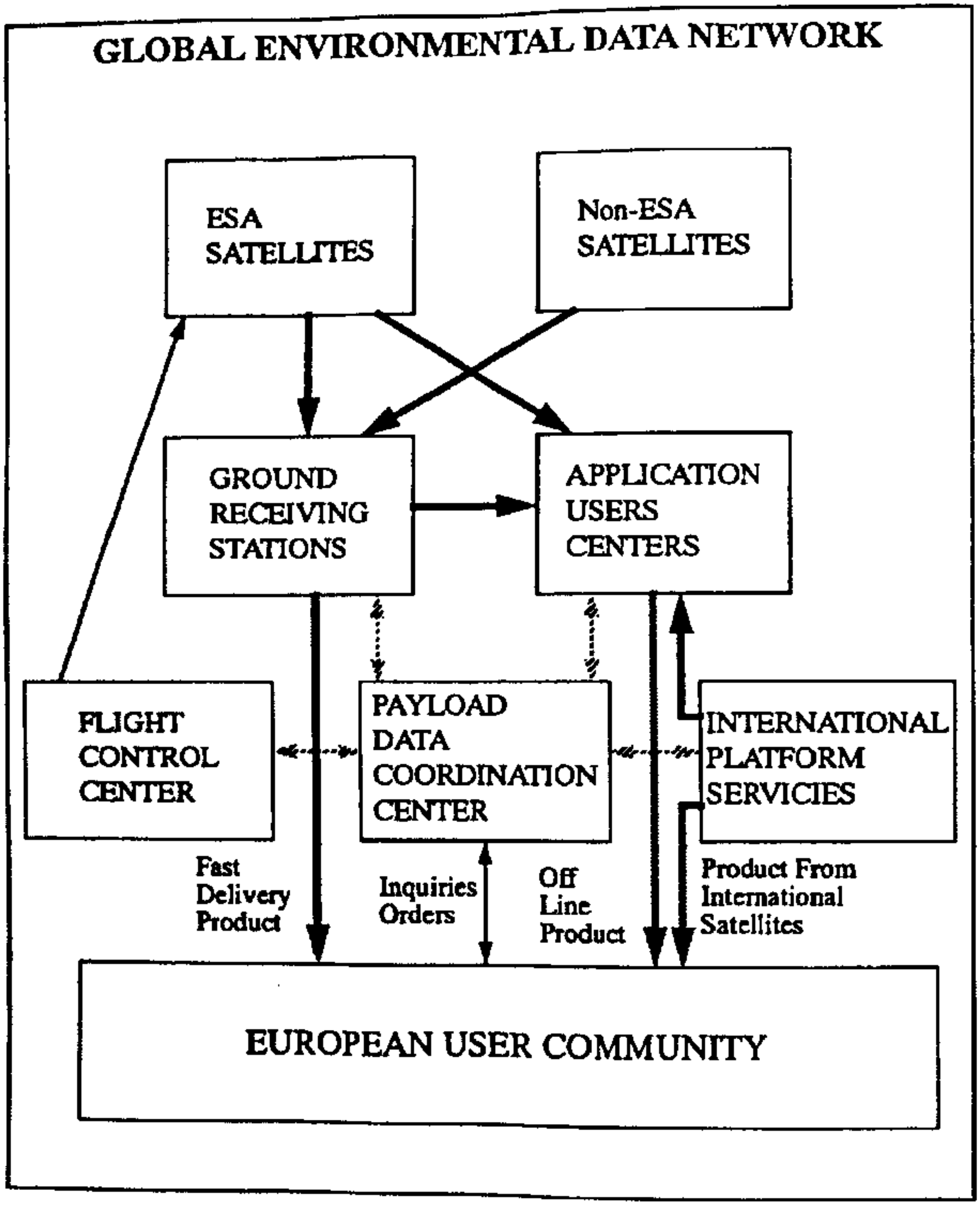

Figure 3. Conceptualization of the Global Environmental Data Network being developed by the European Community (based on material in Fusco, 1992). Large black arrow indicates data flow, small black arrow indicates message and control flow, large grey arrow indicates product delivery line to end user, and small hatched grey arrow indicates coordination between activities.

implemented centralized services; (3) Phase 3 (by 1997) full evolution of the data communications network to handle data from the international space platforms as well as all historical data of interest (Fusco, 1992). Like GRID, the Global Environmental Data Network is not specifically designed around the support of an operational fishery. It should, however, provide the type of data network infrastructure required to support a fishery in near-real time.

CONCLUSIONS

The aggressive development and investment by non-U.S. fishing industries in the transfer of remote-sensing and geographic information system technologies to their operational commercial fishing fleets could render the U.S. commercial fishing fleet noncompetitive within the U.S. Exclusive Economic Zone. Moreover, strategies are currently in place to make this technology portable. Once implemented, such portable strategies would place the U.S. commercial fishing fleet at an extreme disadvantage in most remote major world fisheries (i.e., those outside the U.S. Exclusive Economic Zone).

During August 1990, a California Sea Grant meeting was held at the University of California, San Diego, where a briefing was given to selected members of the California fishing and seafood industries. It was clear from this meeting that a significant deficiency currently exists in the U.S. commercial fleet's utilization of remote-sensing products. Moreover, it was recognized by these industry people that stock assessment managers need more information to properly manage the U.S. EEZ. This latter point is amply illustrated in the decline of the Canadian Grand Banks Cod Fishery, where total allowable catches were recently reduced by about 40% because of incorrect prior assessment of fish stocks and fecundity. Part of the inability of Canadian stock assessment managers to accurately develop proper forecasts of the strength of the cod fishery was directly related to a lack of information on which to base the total allowable catches.

This report provides the basis for assembling a U.S. team of industry, resource management, and academic people to focus on implementing a U.S. strategy for the development of a remote sensing/geographic information system for use by the operational fisheries oceanography community in the U.S. Exclusive Economic Zone. The combination of remote sensing capabilities with a geographic information system and its associated databases (e.g., hydrographic; bathymetric) can help eliminate the historical deficiencies in satellite support of operational fisheries—namely, no support for mid- and deep-water species and absence of information if clouds are present. Moreover, the strategy of an RS/GIS system, updated in near-real time, provides the possibility for a new and dynamic approach to fisheries resource management by federal and state assessment personnel.

Implementation of such a U.S. capability requires, at the very minimum, careful consideration of the following key points:

1. Optimal satellite-directed support of a pelagic fishery is obtained by combining thermal data (e.g., AVHRR), ocean color data (e.g., CZCS, SeaWIFS) and fish catch statistics in near-real time.

2. Support of a nonpelagic fishery requires the use of geographic information system technologies.

3. In general, remote-sensing and geographic information system technologies should be combined for optimal support of an operational fishery. This approach overcomes the traditional

limitations of the use of remote-sensing alone: (1) lack of support for mid- and bottom-water fisheries; and (2) complete absence of information under heavy cloud conditions. Moreover, the GIS technology provides a rational basis for database management, archiving, distribution, and computer-assisted decision making absent in non-GIS fisheries support applications.

4. Several countries have made substantial progress in the development of a combined RS/GIS approach to support their global marine fishing activities. Unfortunately, the United States, to date, has provided relatively little support by comparison for such development activities, even within the context of the utilization and management of its own Exclusive Economic Zone.

5. Careful consideration must be given to the design and implementation of a wide bandwidth data communications network within the United States. This network is required to efficiently collect, archive, process and distribute in near-real time all the products needed by the U.S. operational fisheries oceanography community. These products will be developed using future spacecraft data in combination with near-real time *in situ* and historical observations.

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